Sewage Works

EFFECT OF TEMPERATURE ON BIOCHEMICAL OXIDATION OF SEWAGE *

By Harold B. Gotaas

Professor of Sanitary Engineering, University of California, Berkeley, Calif.

The assimilation, destruction, oxidation and final stabilization of organic material by living organisms in the presence of oxygen has taken place in nature since the origin of life. This phenomenon has been recognized and studied for the past 75 years by workers in the field of sanitation. From these studies has come information concerning biochemical oxidation of organic material, the widely used B.O.D. test, and the generally accepted formulations and constants in regard to the effect of temperature on biochemical oxidation. However, there is decidedly conflicting data in the limited information available on the effect of temperature on biochemical oxidation of sewage.

The objectives of this investigation include the following: (1) further study of the validity of the Phelps mathematical formulation and other formulations for the trend of the first-stage B.O.D., including the probable errors in the constants of the mathematical formulation; (2) the magnitude of the rate of oxidation at different temperatures; (3) the relationship between the temperature and the rate of oxidation, including the formulation for the relationship; (4) the effect of temperature on the magnitude of the ultimate first-stage B.O.D.; (5) the effect of temperature on the lag period of the first stage of biochemical oxidation; (6) the effect of temperature on the time required to establish the second stage of oxidation; and (7) the rate and magnitude of the second stage.

Experimental Procedure

Before starting the research reported here, the experience of others was investigated and preliminary experimental studies were made. One aspect of importance was the feasibility of using a synthetic sewage as a source of organic matter for biochemical oxidation so that once a satisfactory synthetic sewage formula has been determined, the sewage could be duplicated for all experiments. These studies indicated that the hazards of translating results obtained from investigations using synthetic sewage to use in connection with domestic sewage were such that it would be more satisfactory to use domestic sewage for the studies, even though the sewage would not be the same for each experiment.

Different series of experiments (A1, A2, A3, A4, B, C, D, E and F) were made, in which diluted sewage was incubated at different temperatures ranging from 5° C. to 40° C. to determine the characteristics of the biochemical oxygen demand. The excess oxygen method for determining B.O.D. was used throughout the investigation. Domestic sewage which had been filtered through cotton was diluted with standard sodium bicarbonate water (1), phosphate buffer water (1), or—in Series A2, A3 and A4—mixtures of

* Presented at the Twentieth Annual Meeting, Federation of Sewage Works Assns., San Francisco, Calif., July, 1947.

sodium bicarbonate water and sea water. The sodium azide modification of the Winkler method, as described by Ruchhoft (2), was used for all dissolved oxygen determinations. Mixtures of sewage, dilution water and acclimated seeding material were syphoned into 300-ml. ground glass stoppered bottles, and incubated under water at the respective temperatures. The dilution water was allowed to stabilize several days, then brought to the temperature of the test for which it was to be used.

Each experiment at a certain temperature was seeded with a sewage-dilution water mixture which had been incubated and acclimated for at least two weeks at the particular temperature for which it was to be used. The seed was prepared by mixing sewage and polluted stream water with the specific dilution water at a concentration such that the dissolved oxygen was not depleted during the period of acclimatization.

To avoid any systematic error between the first and last bottles filled, due to improper mixing or aeration, the bottles were numbered and the first and last filled were titrated first, the second and next to the last, next, etc. Two bottles were tested for dissolved oxygen each day during the early part of the B.O.D. curve, and after the curve leveled off one bottle was examined at a time, except when it appeared that the observation might be slightly in error; then the second bottle was tested. The initial dissolved oxygen content of a series was required to check within 0.1 p.p.m. between the bottles titrated. Blanks were incubated to determine the B.O.D. of the dilution water and seed. The temperature of the water bath incubators was, in general, controlled at $\pm 0.1°$ to $\pm 0.2°$ C., of the stated temperatures. When setting up a series of tests using the same sewage throughout, the sewage was chilled to 2° C., thus keeping at a minimum any B.O.D. changes which might take place during the few hours required to make the dilutions, fill the bottles, etc. Tests showed that there was no determinable change in the B.O.D. of the sewage during that period when the sewage temperature was kept at 2° C.

Test Series

Series A1, A2, A3 and A4 contained 1.48 per cent Cambridge, Mass., raw sewage filtered through cotton, and 0.98 per cent seed. As shown in Table I, sodium bicarbonate dilution water was used at temperatures of 5°, 10°, 15°, 20°, 25°, and 30° C. A dilution water mixture of one-third sea water and two-thirds sodium bicarbonate water, having a chloride content of 6100 p.p.m., was used for A2 as shown in Table II. A dilution water mixture of two-thirds sodium bicarbonate water and one-third sea water, having a chloride content of 12,200 p.p.m., was used for A3, as shown in Table III, and straight sea water having a chloride content of 18,300 p.p.m. was used for A4, as shown in Table IV. The dilutions containing sea water (A2,

TABLE I.—Constants for First-Stage B.O.D. (Series A1)

Temp. (° C.)	Dilution Water	Rate Constant (k)	Probable Error	Ultimate B.O.D. (L) in P.P.M.	Probable Error	Lag (days)
5	Bicarbonate	0.06585	±0.00557	238	±25	3.32
10	Bicarbonate	0.08149	±0.00920	228	±32	0.55
15	Bicarbonate	0.15513	±0.00794	224	±15	0.56
20	Bicarbonate	0.17215	±0.00744	230	±13	0.00
25	Bicarbonate	0.23058	±0.01362	259	±18	−0.16
30	Bicarbonate	0.30349	±0.00765	278	± 8	0.03

TABLE II.—Constants for First-Stage B.O.D. (Series A2)

Temp. (° C.)	Dilution Water	Rate Constant (k)	Probable Error	Ultimate B.O.D. (L) in P.P.M.	Probable Error	Lag (days)
5	6,100 p.p.m. Cl	0.06348	±0.00329	254	±17	1.01
10	6,100 p.p.m. Cl	0.15098	±0.00530	263	±12	0.54
15	6,100 p.p.m. Cl	0.17745	±0.00371	252	± 7	0.05
20	6,100 p.p.m. Cl	0.27618	±0.01430	235	±16	−0.07

TABLE III.—Constants for First-Stage B.O.D. (Series A3)

Temp. (° C.)	Dilution Water	Rate Constant (k)	Probable Error	Ultimate B.O.D. (L) in P.P.M.	Probable Error	Lag (days)
5	12,200 p.p.m. Cl	0.07549	±0.00384	247	±16	0.62
10	12,200 p.p.m. Cl	0.13036	±0.00481	235	±11	0.11
15	12,200 p.p.m. Cl	0.20254	±0.00322	237	±15	0.00
20	12,200 p.p.m. Cl	0.28582	±0.02470	236	±20	0.03

TABLE IV.—Constants for First-Stage B.O.D. (Series A4)

Temp. (° C.)	Dilution Water	Rate Constant (k)	Probable Error	Ultimate B.O.D. (L) in P.P.M.	Probable Error	Lag (days)
5	18,300 p.p.m. Cl	0.09771	±0.00374	243	±12	1.04
10	18,300 p.p.m. Cl	0.12850	±0.00482	241	±11	0.04
15	18,300 p.p.m. Cl	0.19181	±0.00475	247	± 8	−0.01
20	18,300 p.p.m. Cl	0.26029	±0.02015	247	±24	−0.03

TABLE V.—Constants for First-Stage B.O.D. (Series B)

Temp. (° C.)	Dilution Water	Rate Constant (k)	Probable Error	Ultimate B.O.D. (L) in P.P.M.	Probable Error	Lag (days)
12	Bicarbonate	0.09539	±0.00855	122	±13	0.08
12	Phosphate	0.09399	±0.00772	133	±14	1.57
20	Bicarbonate	0.16117	±0.00769	138	± 8	−0.01
20	Phosphate	0.17703	±0.00608	144	± 6	−0.16

TABLE VI.—Constants for First-Stage B.O.D. (Series C)

Temp. (° C.)	Dilution Water	Rate Constant (k)	Probable Error	Ultimate B.O.D. (L) in P.P.M.	Probable Error	Lag (days)
12	Phosphate	0.08966	±0.01702	375	±57	1.10
20	Bicarbonate	0.15970	±0.00429	358	±11	0.01
20	Phosphate	0.18047	±0.00515	303	±12	0.06

A3, and A4) were incubated at 5°, 10°, 15°, and 20°.

Series B contained 1.95 per cent domestic settled sewage from Chapel Hill, N. C., filtered through cotton, and 0.49 per cent seed in standard phosphate buffer and sodium bicarbonate water, and was incubated at 12° C. and 20° C., as shown in Table V.

Series C contained 2.83 per cent

Chapel Hill settled sewage, filtered through cotton, and 2.83 per cent seed in standard phosphate buffer and bicarbonate water, and was incubated at 12° C. and 20° C., as shown in Table VI.

Series D, shown in Table VII, contained 1.95 per cent Chapel Hill domestic sewage, filtered through cotton, and 0.49 per cent seed in the standard sodium bicarbonate dilution water, and was incubated at 5°, 10°, 15°, 20°, 25°, 30°, 35°, and 40° C. Phosphate dilution water was also used at 20° C.

Series E, shown in Table VIII, contained 2.1 per cent Chapel Hill domestic sewage and 0.49 per cent seed at 5° C.; 2.42 per cent sewage and 0.49

TABLE VII.—Constants for First-Stage B.O.D. (Series D)

Temp. (° C.)	Dilution Water	Rate Constant (k)	Probable Error	Ultimate B.O.D. (L) in P.P.M.	Probable Error	Lag (days)
5	Bicarbonate	0.04791	±0.00391	233	±23	1.11
10	Bicarbonate	0.12535	±0.00684	217	±15	1.21
15	Bicarbonate	0.16214	±0.00276	222	± 5	0.51
20	Bicarbonate	0.18718	±0.00257	236	± 4	0.06
20	Phosphate	0.20517	±0.00648	217	± 9	−0.03
25	Bicarbonate	0.18540	±0.00605	238	±10	−0.22
30	Bicarbonate	0.25506	±0.01162	267	±15	−0.03
35	Bicarbonate	0.28417	±0.00916	244	±10	−0.10
40	Bicarbonate	0.21915	±0.01856	231	±25	−0.20

TABLE VIII.—Constants for First-Stage B.O.D. (Series E)

Temp. (° C.)	Dilution Water	Rate Constant (k)	Probable Error	Ultimate B.O.D. (L) in P.P.M.	Probable Error	Lag (days)
5	Bicarbonate	0.04653	±0.00800	236	±47	3.09
10	Bicarbonate	0.06412	±0.00516	230	±22	0.70
10	Phosphate	0.07075	±0.00605	239	±25	1.08
15	Bicarbonate	0.11723	±0.00436	247	±11	0.47
20	Bicarbonate	0.16410	±0.00833	249	±16	−0.01
20	Phosphate	0.18730	±0.01278	218	±19	0.71
25	Bicarbonate	0.19337	±0.01016	240	±15	−0.02
30	Bicarbonate	0.25784	±0.01020	242	±12	0.03
34	Bicarbonate	0.21578	±0.00771	257	±11	−0.20
40	Bicarbonate	0.19719	±0.00801	268	±13	−0.13

TABLE IX.—Constants for First-Stage B.O.D. (Series F)

Temp. (° C.)	Dilution Water	Rate Constant (k)	Probable Error	Ultimate B.O.D. (L) in P.P.M.	Probable Error	Lag (days)
5	Bicarbonate	0.16488	±0.00798	104	± 5	1.21
10	Bicarbonate	0.12282	±0.00671	146	± 6	0.190
10	Phosphate	0.18529	±0.01080	123	± 9	0.41
15	Bicarbonate	0.16090	±0.02010	138	±22	−0.07
20	Bicarbonate	0.24120	±0.01272	148	±10	−0.10
20	Phosphate	0.24420	±0.01043	146	± 8	−0.22
25	Bicarbonate	0.30294	±0.01017	159	± 7	−0.06
30	Bicarbonate	0.27091	±0.00684	210	± 6	−0.04
35	Bicarbonate	0.22300	±0.01600	225	±20	−0.27
40	Bicarbonate	0.16930	±0.01868	256	±36	−0.35

per cent seed at 10° C.; 1.95 per cent sewage and 0.49 per cent seed at 15°, 20°, 25°, and 30° C.; and 1.47 per cent sewage and 0.49 per cent seed at 34° and 40° C. Sodium bicarbonate dilution water was used at each temperature, and in addition, phosphate buffer water was used at 10° C. and 20° C.

Series F, shown in Table IX, contained 1.94 per cent Chapel Hill domestic sewage and 0.97 per cent seed. The dilution waters and temperatures are the same as shown for Series D, except that phosphate buffer dilution water was used at 10° C. and at 20° C.

Experimental Results and Discussion *

The detailed results of B.O.D. observations and the calculated values which compare with the individual observations are not tabulated here because of the space required. Figures 1 to 9 show graphically the biochemical oxygen demand curves of best fit, and the observations at the different temperatures of all the series of experiments.

Because of the difficulty of showing in the figures so many points which, when two bottles were titrated at the same time, often were identical, the average of the two is plotted. However, each observation, rather than the average, was used to compute the curve of best fit to the observations.

To avoid making Figures 1 to 9 inclusive so large, only observations up to 34 days are shown. Observations at 5° C. and 10° C. were made for periods as long as 67 days, and at 15° C., as long as 45 days. At 5° C. the observations above 34 days mainly show a gradual increase in the B.O.D. At 10° C., the observations in Series D, E and F gradually increase in magnitude until a second stage is indicated at from 45 days to over 67 days. The magnitude of the individual observations after 34 days may be found in the footnote reference previously cited.

A short verticle line across a curve in Figures 1 to 9 indicates that only the observations to the left of that line were used to compute the constants of the equation for the curve.

Many of the curves for the second stage of oxidation shown in Figures 1 to 9 are fitted by eye rather than by least squares, since there were too few observations, or the observations were too erratic for mathematical curve fitting. In these cases, no value for k is shown in Table XV.

Formulation of Biochemical Oxygen Demand Curve

In investigating the mathematical formulation of the curve of best fit to the biochemical oxygen demand observations, the unimolecular equation first proposed by Phelps (3) and the inclusion of the lag period fit the data better than any of the other formulations studied:

$$\log \frac{L}{L-X_t} = k(t-t_0)$$

or

$$X_t = L[1-10^{-k(t-t_0)}]$$

or

$$X_t = L(1-10^{-kt})$$

where L = total demand of the stage
X_t = oxygen used up at any time t
K = rate constant for a given set of conditions
t_o = the value of t at the end of the lag period, that is, the value of t when $X_t = 0$.

The "slope method" of Thomas (4) (5) was used to compute the rate constant k, the ultimate stage demand L, and the lag-period t_o, since the accuracy

* A dissertation "Biochemical Oxidation of Sewage in Fresh and Brackish Waters at Different Temperatures," by H. B. Gotaas, containing the individual experimental results and a more extensive analysis and study of the information than is feasible to present here, is in the library of Harvard University, Cambridge, Mass., and the library of the University of North Carolina, Chapel Hill, North Carolina.

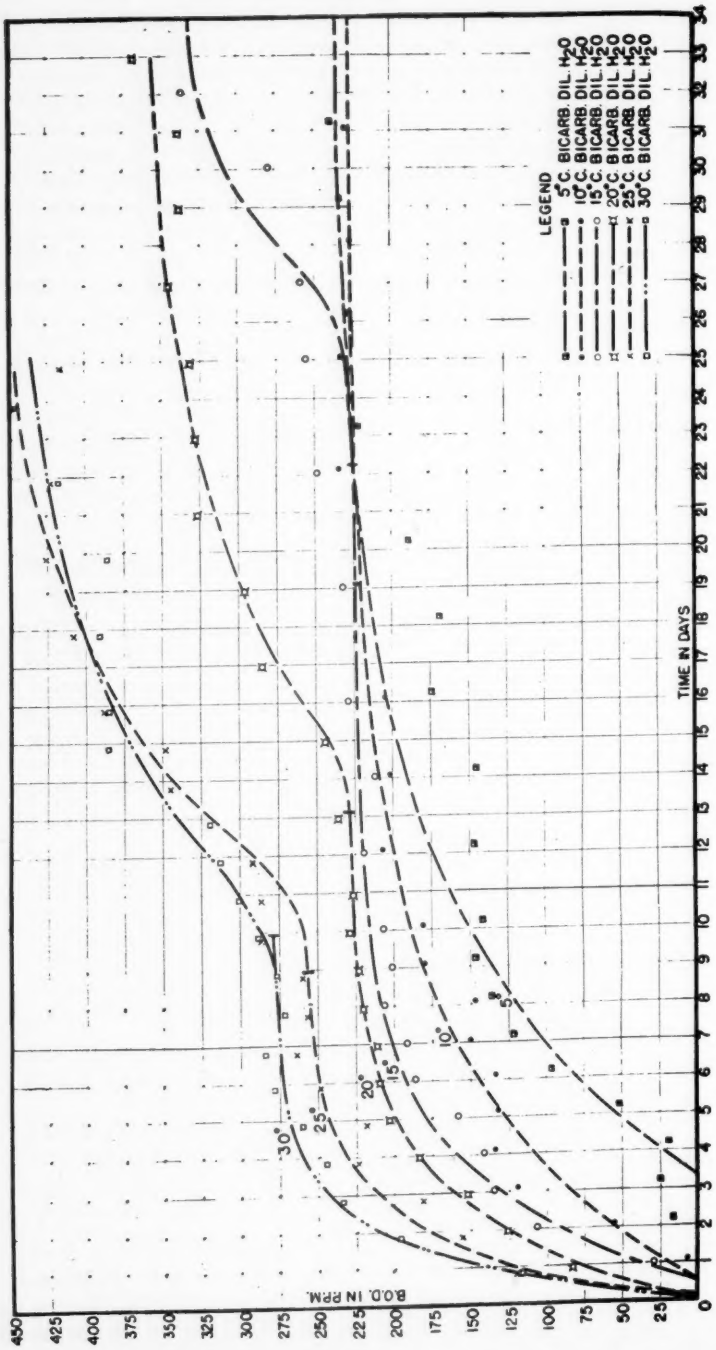

FIGURE 1.—B.O.D. Series A1.

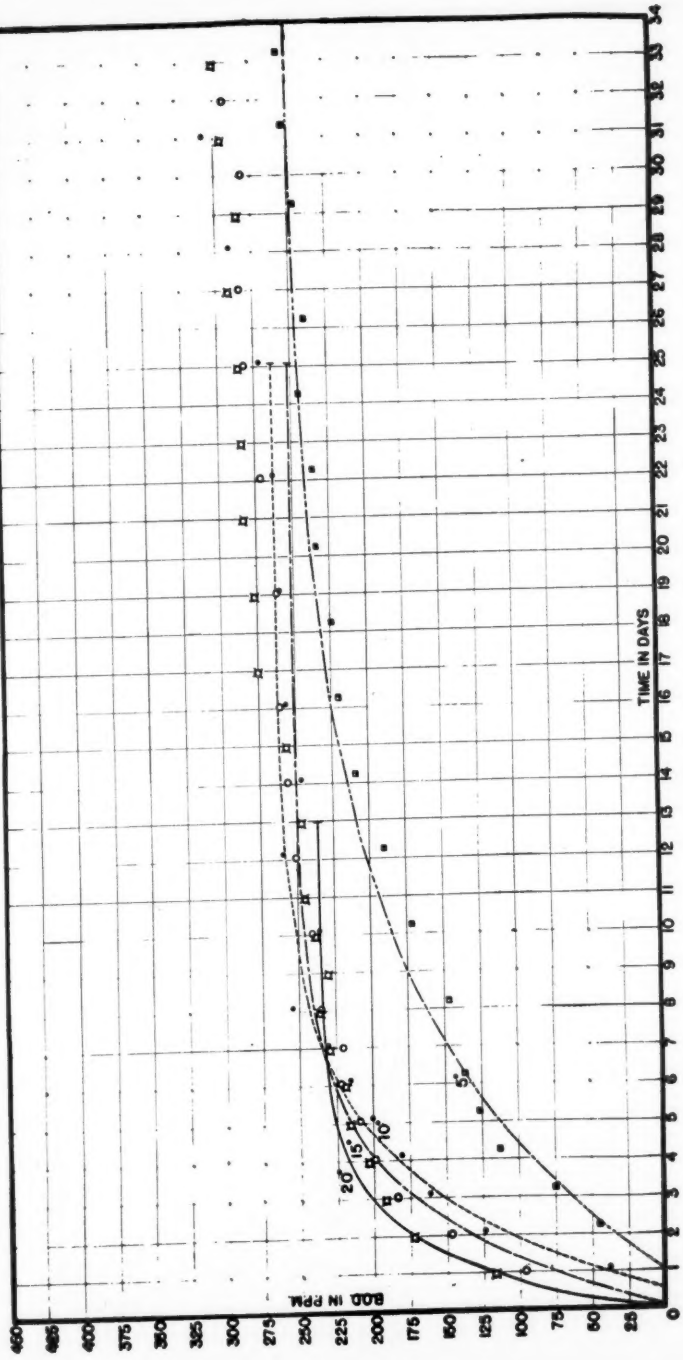

FIGURE 2.—B.O.D. Series A2.

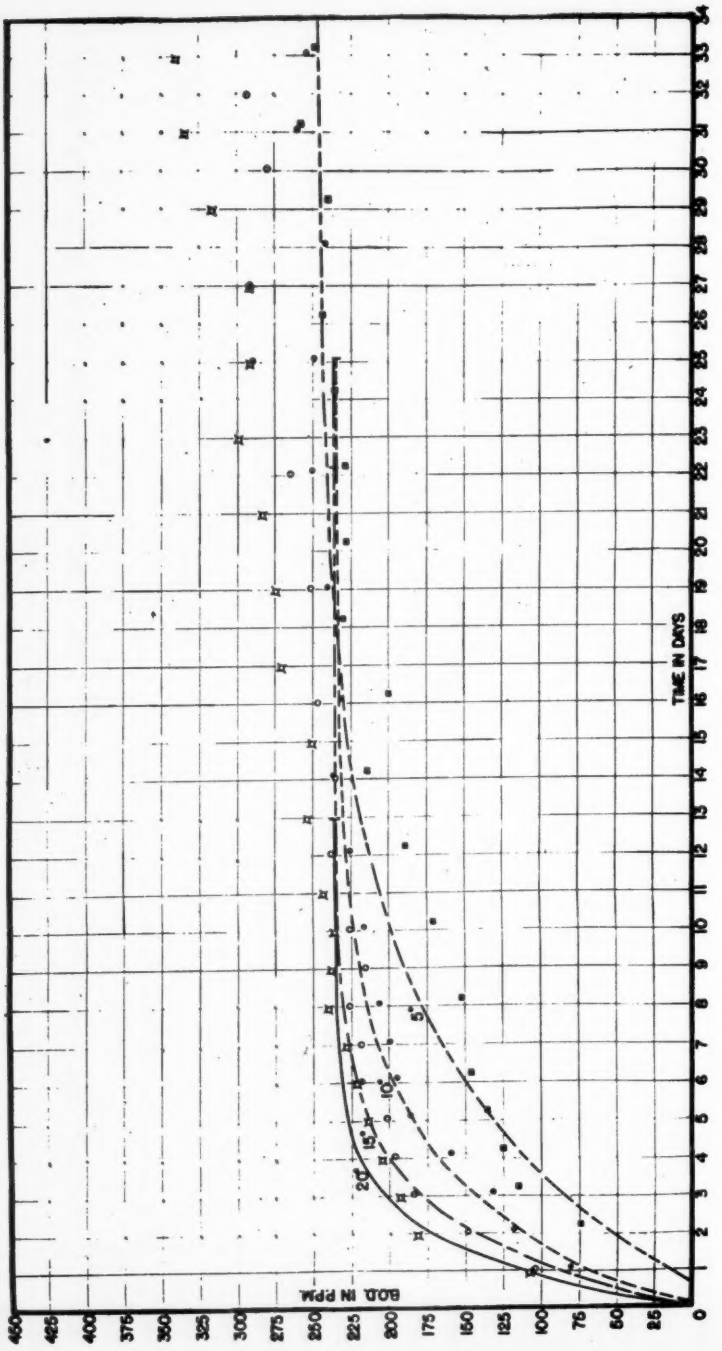

FIGURE 3.—B.O.D. Series A3.

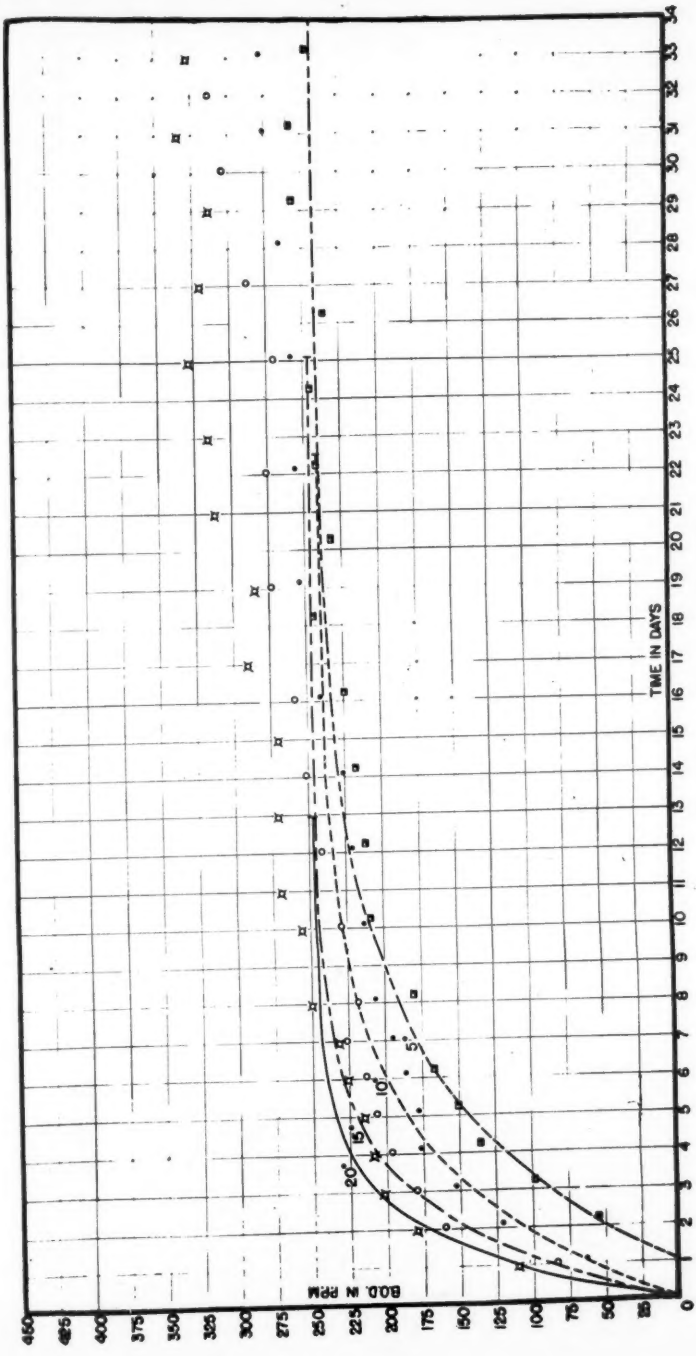

FIGURE 4.—B.O.D. Series A4.

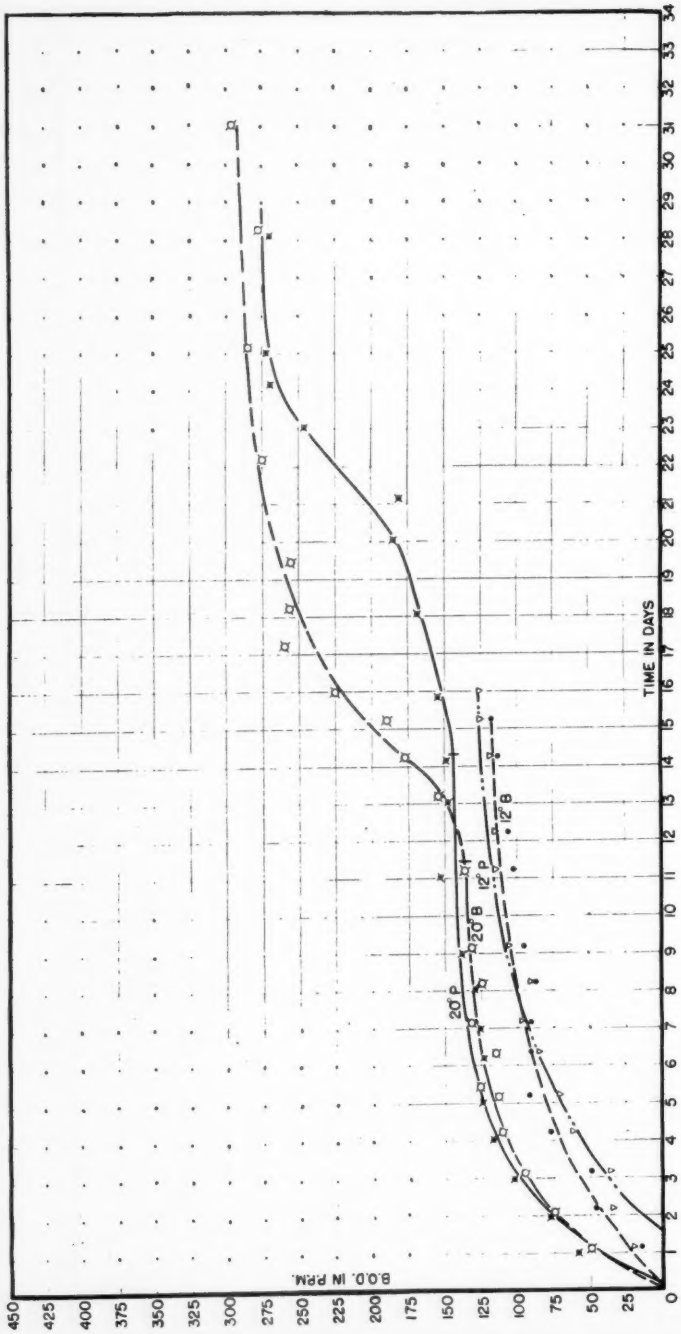

FIGURE 5.—B.O.D. Series B.

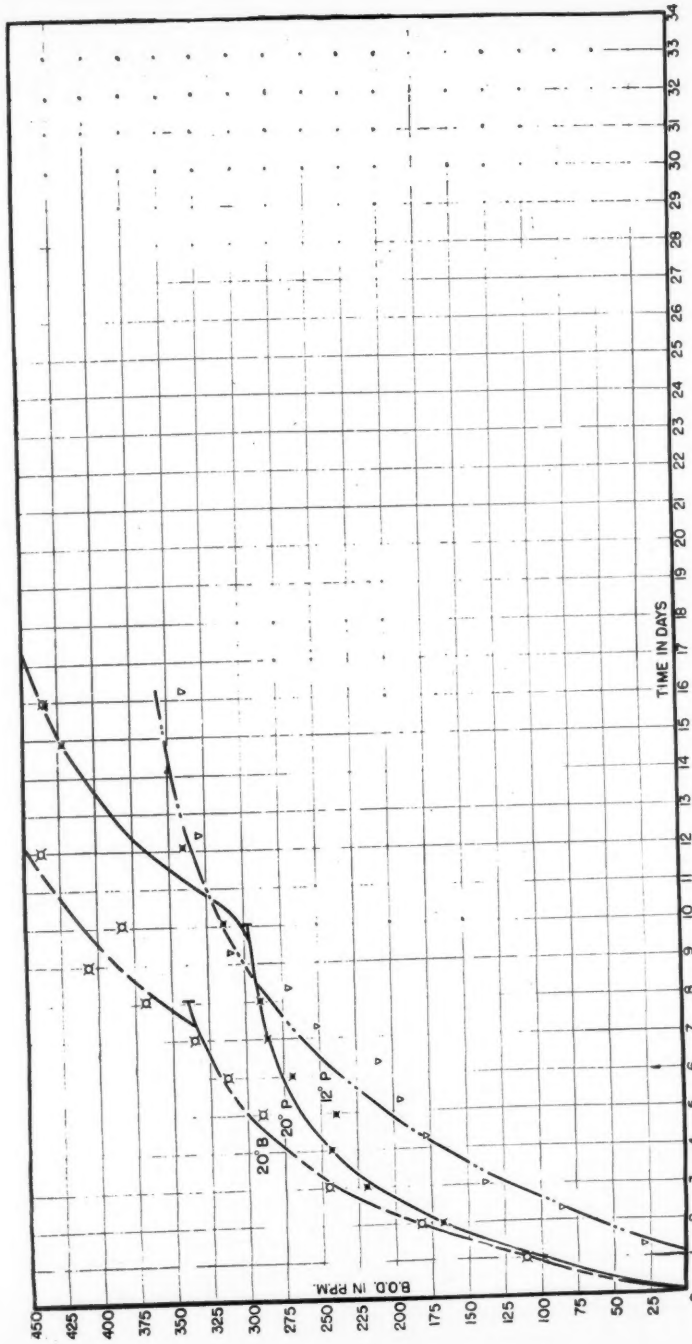

FIGURE 6.—B.O.D. Series C.

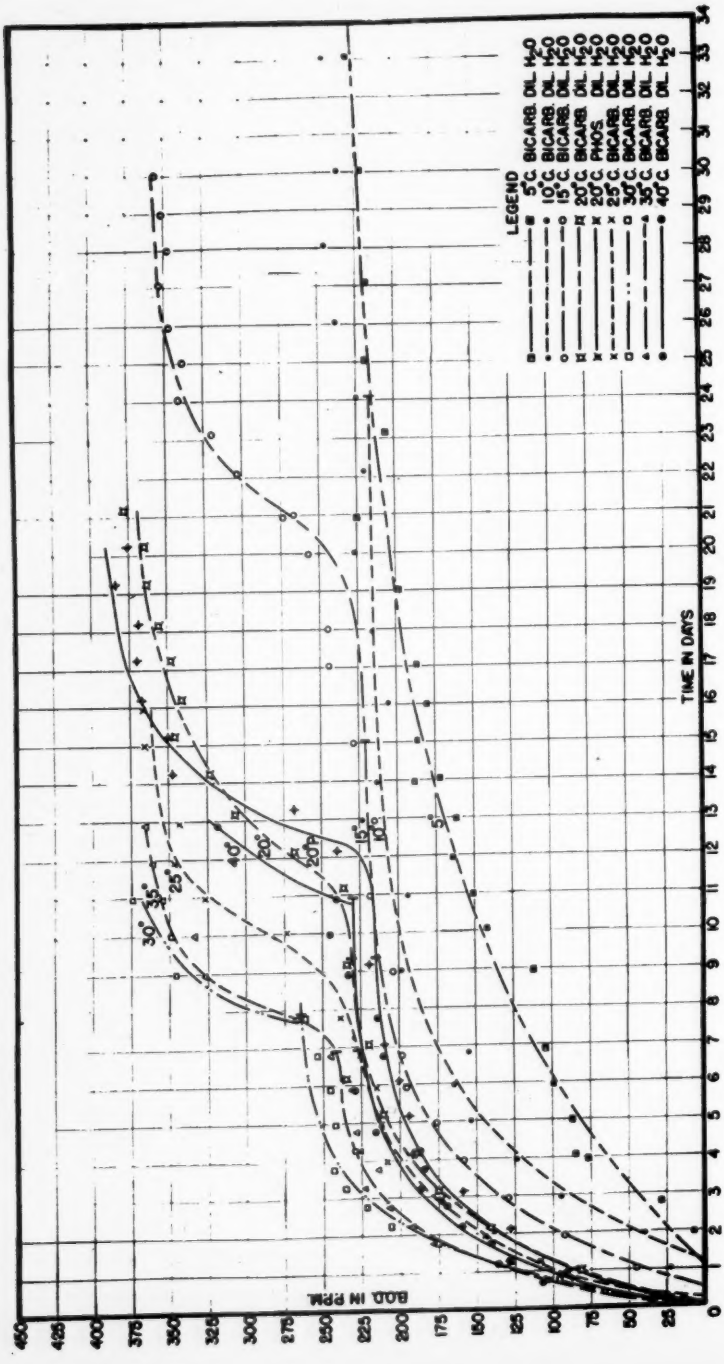

FIGURE 7.—B.O.D. Series D.

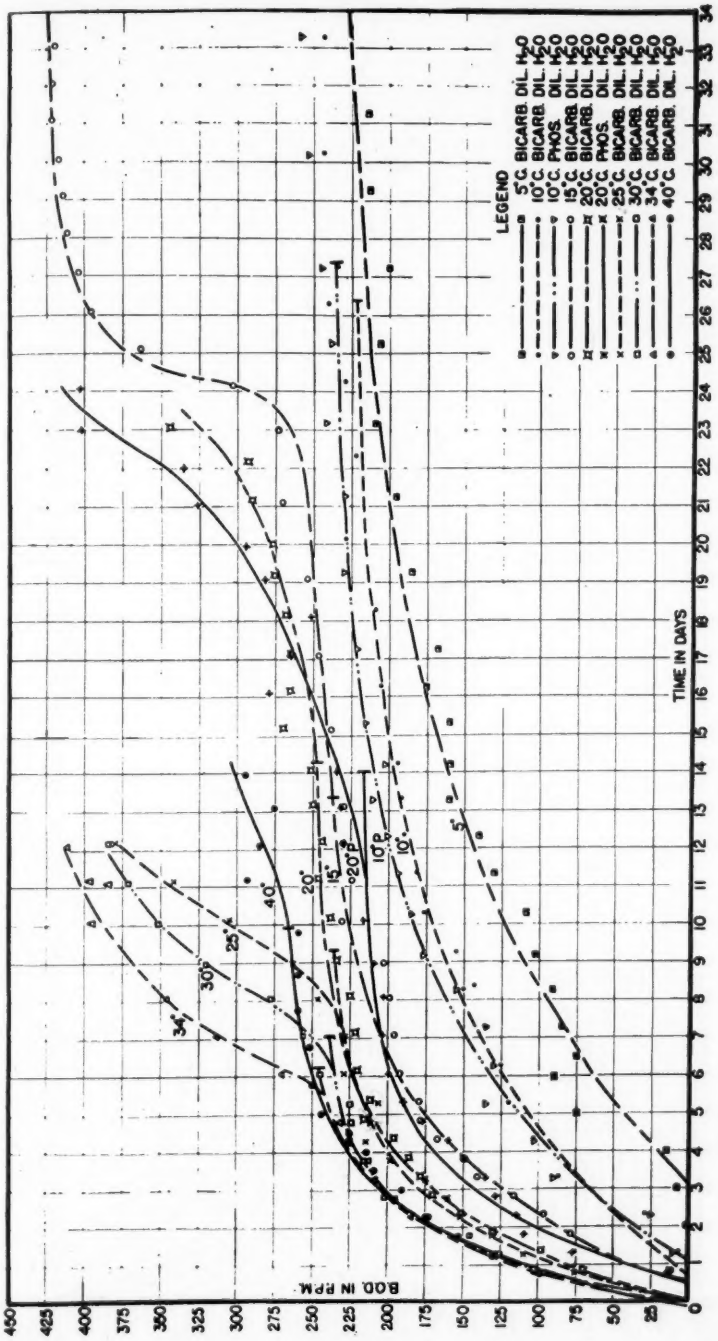

FIGURE 8.—B.O.D. Series E.

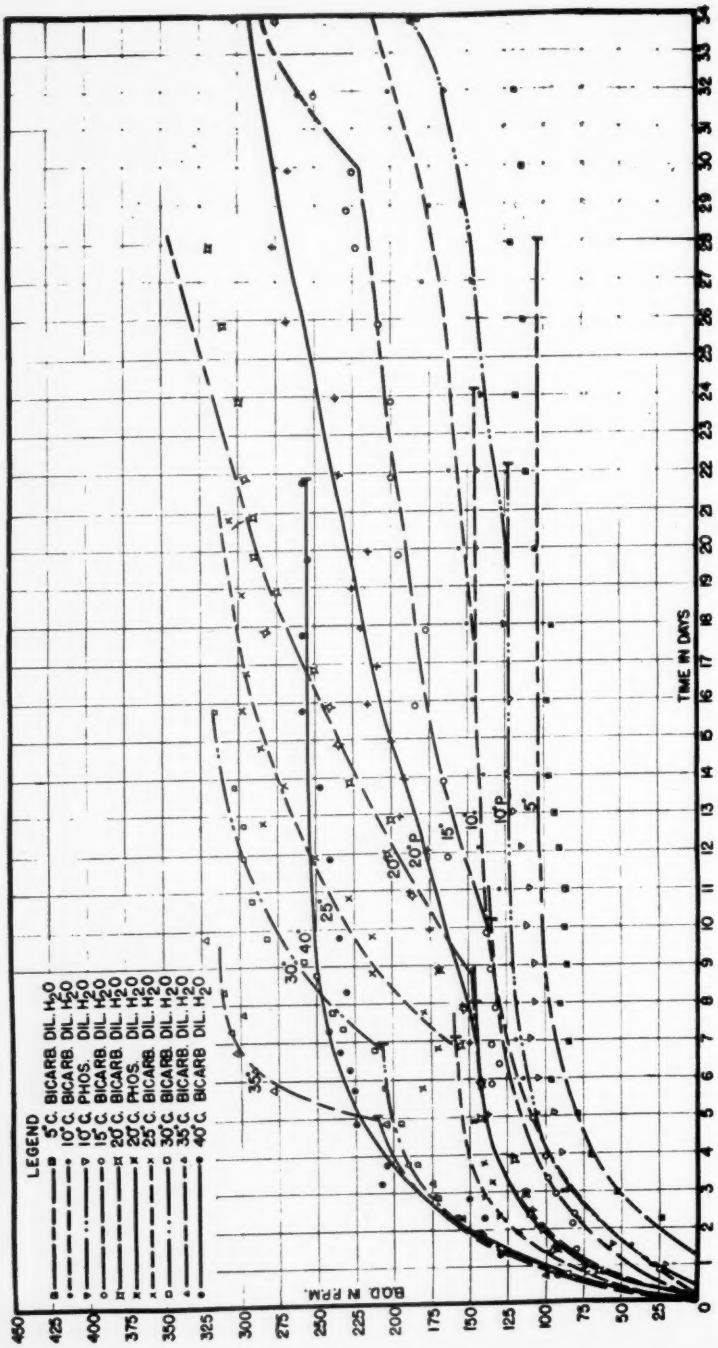

FIGURE 9.—B.O.D. Series F.

of the method is as great, and it is much more readily applied than the methods of Reed and Theriault (6) and Fair (7).

Tables I to IX, inclusive, show the rate constants k, the ultimate first-stage demands L, and the lag periods t_o, together with the probable errors in k and L, for the experiments of Series A1, A2, A3, A4, B, C, D, E and F, respectively.

Table X shows the probable errors in k and L as a per cent of the respective values of k and L. In analyzing the probable errors in k and L, it should be again mentioned that each observation for oxygen depletion—which was one incubated bottle taken off—was used as a point in the calculation of the constants for the curves, as contrasted with the procedure of Theriault (8) and Moore (9), in which the average of two observations made at one time is used as a point in the calculation of the constants. One would, therefore, expect the probable error of the constants for the curves presented here to be about twice as large as when two observations are averaged.

It is seen that in general the probable errors in k and L are greatest at 5° C., and become smaller with each 5° C. increase in temperature up to 15° C. The average probable errors at the respective temperatures between 15° C. and 35° C., are low and of the same general order of magnitude, except for the 15° C. experiment of Series F. The 40° C. curves show that biochemical oxidation does not take place as uniformly at this temperature as in the middle range of temperatures, possibly because 40° C. is near the upper limit of the temperature range for mesophilic bacteria.

The larger probable errors in the constants for the curves at 5° C. and 10° C. indicate the lack of uniformity

TABLE X.—Probable Percentage Errors in k and L for the Bicarbonate and the Phosphate Water Experiments (Series A to F) at Different Temperatures

Temp. (° C.)	Series A1		Series B		Series C		Series D		Series E		Series F		Average P.E. in k	Average P.E. in L
	P.E. in k (%)	P.E. in L (%)	P.E. in k (%)	P.E. in L (%)	P.E. in k (%)	P.E. in L (%)	P.E. in k (%)	P.E. in L (%)	P.E. in k (%)	P.E. in L (%)	P.E. in k (%)	P.E. in L (%)		
5	8.5	10.5	—	—	—	—	8.1	9.9	17.2	19.9	4.8	4.8	9.6	11.3
10	11.3	14.0	—	—	—	—	5.4	6.9	8.1	9.6	5.5	4.1	7.5	9.7
10	—	—	—	—	—	—	—	—	(8.6)	(10.5)	(5.8)	(7.3)	(7.2)	(9.9)
12	—	—	8.9	10.7	—	—	—	—	—	—	—	—	—	—
12	—	—	(8.2)	(10.5)	(19.0)	(15.2)	—	—	—	—	—	—	—	—
15	5.1	6.7	—	—	—	—	1.7	2.3	3.7	4.5	12.5	15.9	6.2	8.0
20	4.3	5.7	4.8	5.8	2.7	3.1	1.4	1.7	5.1	6.4	5.3	6.8	3.9	4.9
20	—	—	(3.4)	(4.2)	(2.8)	(4.0)	(3.1)	(4.2)	(6.8)	(8.7)	(4.3)	(5.5)	(4.1)	(5.3)
25	5.9	6.9	—	—	—	—	3.3	4.2	5.2	6.3	3.4	4.4	4.4	5.5
30	2.5	2.9	—	—	—	—	4.6	5.6	3.7	5.0	2.5	2.9	3.3	4.1
34	—	—	—	—	—	—	—	—	3.6[1]	4.3[1]	—	—	—	—
35	—	—	—	—	—	—	3.2	4.1	—	—	7.2	8.9	4.7	5.8
40	—	—	—	—	—	—	8.5	10.7	4.1	4.9	11.0	14.1	7.9	9.9

[1] Averaged with 35° C. observations.

or regularity with which biological oxidation proceeds in some cases at these temperatures. It may be seen from the 5° C. curves of Figures 1, 7, and 8, and the 10° C. curve of Figure 8, that some of the observations for these curves tend to show a flattening and break characteristically similar to that of a second or nitrification stage. In experiments where this break occurs, the k for the part of the curve representing the first few days of oxidation is much larger than that of the curve fitting the later observations. Some of the low temperature curves in Moore's studies (9) also show this tendency to exhibit a pseudo second stage during the first few days of oxidation. Moore has suggested that the so-called "first stage" may be composed of two or more stages which are indistinguishable at the higher temperatures, but become apparent at the low temperatures where the reaction velocities are low. A quite probable reason for this characteristic is the acclimatization of the bacteria. All experiments were seeded with acclimatized organisms, but there were also other organisms in the sewage. Since the organisms in the sewage were not acclimatized to the conditions of incubation, it is possible that the acclimatized organisms multiplied and produced enzymes more rapidly at the lower temperature and thus predominated at the start, only to be dominated later by some other organism which was slower to develop at the lower temperatures.

The value of k and L will vary somewhat, according to the number of observations used for the computation. For example: if only those observations of, say, the first 5 or 7 days are used, k and L will differ from the values obtained if 12 days' observations are used. It may be seen that in several cases after the B.O.D. observations leveled off, they ceased to be unimolecular, and the deoxygenation observations increased almost as a straight line. It is believed that possible nitrification begins before a pronounced second stage is noticeable, and actually both the first and second stage are going on at the same time. Theriault (8) observed this characteristic in his 9° C. curves, and used only the observations of the first 24 days to compute k and L. Mohlman, Edwards and Swope (10) observed that deoxygenation due to nitrification in the second stage may follow a course approximately described by a straight line instead of a logarithmic course.

The general course of deoxygenation and the k values vary somewhat for the six different sewages; however, when it is considered that biological processes deal with the responses of living organisms to their environment and in general do not show the same degree of uniformity and consistency as do purely chemical processes, the results are reasonably consistent.

Values of k at Different Temperatures

The magnitude of k at different temperatures is of great importance in all problems involving biochemical oxidation. The values computed for the fresh water experiments at the different temperatures are shown in Table XI.

At 5° C.

There is reasonably good agreement between the values of k at 5° C., except for Series F. Figure 9 shows that this curve flattened out about the sixth day and did not exert appreciable further oxygen depletion, as contrasted to the 5° C. curves of Series A1, D, and E (Figures 1, 7 and 8, respectively). When the observations just to the break of the 5° C. curves of Series A1, D, and E are used to determine k and L, the following values are obtained:

Series A1, 5° C.; $k = 0.19474$; $L = 159$
Series D, 5° C.; $k = 0.24950$; $L = 113$
Series E, 5° C.; $k = 0.15927$; $L = 108$

TABLE XI.—Observed Value of k at Different Temperatures in Bicarbonate and Phosphate Water

Temp. (° C.)	Series						Average of k values
	A1	B	C	D	E	F	
5	0.06485	—	—	0.04791	0.04653	0.16488[1]	0.05310
10	0.08149	—	—	0.12535	0.06412	0.12282	0.09844
10	—	—	—	—	(0.07075)	(0.18529)	
12	—	0.09539	—	—	—	—	—
12	—	(0.09599)	(0.08966)	—	—	—	(0.09182)
15	0.15513	—	—	0.16214	0.11723	0.16090	0.14885
20	0.17215	0.16117	0.15970	0.18718	0.16410	0.24120	0.18091
20	—	(0.17703)	(0.18042)	(0.20517)	(0.18730)	(0.24420)	(0.19883)
25	0.23058	—	—	0.18540	0.19337	0.30294	0.22807
30	0.30349	—	—	0.25506	0.25784	0.27091	0.27182
34	—	—	—	—	0.21578[2]	—	—
35	—	—	—	0.28417[2]	—	0.22300[2]	0.24098
40	—	—	—	0.21915	0.19719	0.16930	0.19521

( ) shows phosphate water. [1] Omitted in average.
[2] Averaged together and temperature of average taken as 34.67° C.

These values indicate the high rate of oxidation following an initial lag period at 5° C., but this rate is maintained only a short time, and is followed by a much slower rate of oxidation. This condition is also apparent in the brackish water dilutions at 5° C. shown in Figures 2 and 3. But this is not apparent in Figure 4, where the sewage was diluted with straight sea water.

The values of k obtained by neglecting the break in the early part of the observations and fitting one curve to all of the observations appear to be more consistent with the results of other investigators. Moore (9) found the following values for k at 5° C.: 0.0501 with bicarbonate water and 0.0369 with phosphate water for one sewage, and 0.0589 with bicarbonate water and 0.0514 with phosphate water for another sewage. Using distilled water for dilution, Greenfield and Elder (11) found values for k for sewage at 2° C. of 0.0451, 0.0450, 0.0416 and 0.0413.

At 10° C.

The agreement between the values of k at 10°C. for the different sewages is not good. The 10° C. phosphate dilution water curve of Series F shows an abnormally high value for k. It may be seen that very little oxidation took place between the seventh and twentieth days. The 10° C. k values of Series E are lower than the other series, but it should be noted that the k values at all temperatures of Series E are lower than the other series. Moore (9) found values of k for two sewages at 10° C. of 0.0585 and 0.0713 in bicarbonate water and 0.0554 and 0.0904 in phosphate water. Theriault (8) found the k values in four experiments on Ohio River water at 9° C. to average 0.0542.

At 12° C.

The values of k at 12° C. for Series B and C are in good agreement with each other and with the 10° C. and 15° C. values of Series A and E, but are low when compared with Series D and F.

At 15° C.

The agreement between the values of k for the four different sewages is excellent except for Series E, in which k is lower at most of the temperatures. The average of these 15° C. k values is 0.14885, which is about twice as high as the average k of 0.075 that Greenfield and Elder (11) found from six experiments at 14° C. However, it is in the range of magnitude (0.10 to 0.18) computed by Theriault (8) for Adeney's experiments (12) at a temperature of 15° C. to 18° C. It should be noted that by using the "slope" method, and considering lag, still larger values of k for Adeney's experiments are obtained.

At 20° C.

While the Series F curves have a slightly larger k than the other series, there is remarkable agreement in the oxidation rates at this temperature. The average values for k of 0.18091 in bicarbonate water and 0.19883 in phosphate water are much larger; almost twice as large as the value of 0.1 found by Phelps (3) and Theriault (8), and much larger than the values of 0.11 to 0.125 reported by Greenfield and Elder (11). However, Moore (9) reports one value of k of 0.182 for sewage in phosphate water. Pleissner's experiments on Spree River water at 20° C., as calculated by Theriault (8), yield values for k of 0.2106 and 0.2500. Baity (13) obtained values of k for sewage at 20° C. and 25° C. of 0.1326 and 0.1644. Abbott (14), studying biochemical oxidation of sewages and polluted waters at 20° C., found from a large number of tests, varying values for k summarized as follows:

	Max. k	Min. k	Ave. k
Raw sewage	0.290	0.090	0.149
Centrifuged sewage	0.269	0.085	0.143
Creeks	0.246	0.077	0.150
River water	0.152	0.099	0.118
Activated sludge effluents	0.100	0.092	0.098
Filtered sewage	0.366	0.100	0.165

The Committee on Sanitary Engineering of the National Research Council (15), in studying sewage treatment at military installations, reported an average k at 20° C. of 0.18 for sewages from sixteen military installations, with a maximum k of 0.30 and a minimum of 0.10. Ruchhoft, Placak, Kachmar, and Calbert (16) report that the values of k at 20° C. for 59 sewage samples were noticeably greater than the generally accepted value of 0.1. Also, they report that significant variation in k invalidates the conception that the 5-day B.O.D. is proportional to the strength of the sewage. Thomas (17) reports values of k at 20° C. for substances in the solid, colloidal and dissolved phases as follows: solid phase, 0.0642; colloidal phase, 0.166; and dissolved phase, 0.190. This points out the effect of availability of the oxidizable material on the reaction velocity. The organic material in this investigation was largely in the colloidal and dissolved phases, since the sewages were filtered through cotton.

At 25° C.

Except for Series F, the values of k are in close agreement, and the probable error in each case is low. However, in Series D, the value of k is not consistent with the 20° C. and 30° C. values of the same series. Thomas (17) found k for seeded sewage at 23° C. to be 0.178, and Baity (13) found a k of 0.2308.

At 30° C.

The values of k are in close agreement, except for Series A, which is slightly higher. These values do not agree with those found by Theriault (8) on Ohio River water, which range from 0.1277 to 0.1794, and average 0.1543. However, the ratio of the average at 30° C. of this investigation to that of Theriault is practically the same as the ratio between the respective average k values at 20° C.

At 34° C. and 35° C.

Series D and F were incubated at 35° C., and Series E at 34° C. It should be noted that in Series E and F, k is smaller than at 30° C.; while in Series D it is a little larger. This will be analyzed later with the relationship

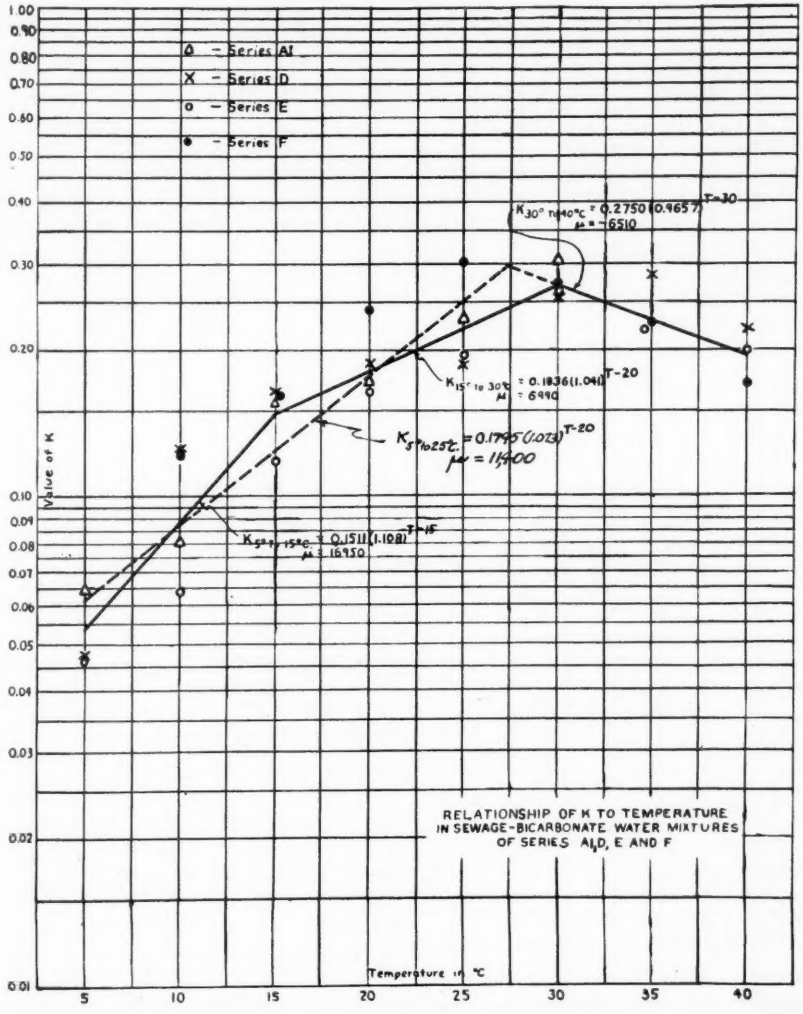
Δ – Series A1
X – Series D
o – Series E
• – Series F
Value of K
Temperature in °C
RELATIONSHIP OF K TO TEMPERATURE IN SEWAGE-BICARBONATE WATER MIXTURES OF SERIES A1, D, E AND F

FIGURE 10.—Relationship of k to temperature in sewage-bicarbonate water mixtures of Series A1, D, E and F.

of k to temperature, where it is shown that the optimum temperature for oxidation appears to be about 30° C., and that k decreases at higher temperatures. There are various reports in the literature of biochemical oxidation experiments at 37° C., but Phelps' determination of the magnitude of k at 37° C. as 0.2 seems to be the only value available. This value lies between the average values for k at 35° C. and at 40° C. found in this investigation. Five tests on settled sewage at 37° C. reported by Abbott (14) show an average k of 0.304, a maximum of 0.430, and a minimum of 0.195.

At 40° C.

The k values are all much lower than at 35° C., and in two cases lower than at 30° C. This indicates that 40° C. is considerably above the optimum temperature for the maximum rate of biochemical oxidation.

It is apparent that the value of k at any temperature for different sewages varies considerably. Also the value of k appears to be considerably larger than the generally accepted value of 0.1 at 20° C., and the related values at other temperatures.

Relationship of Magnitude of k at Different Temperatures

Streeter and Phelps (18) deduced from the data available at that time the following formulation for the first-stage k at various temperatures, which is similar to the equation of Van't Hoff-Arrhenius:

$$k_T = k_{20} \times \theta^{(T-20)}$$

where k_T = value of k at any temperature

$k_{20} = k$ at 20° C. = 0.1

θ (the temperature coefficient) = 1.047.

The formulation has been considered to be applicable within the range 2° C. to around 40° C. Theriault (8) confirmed this value of θ in his studies on biochemical oxidation of Ohio River water.

To analyze the relationship of k to temperature in accordance with the Streeter and Phelps formula, the values of k were plotted to a logarithmic scale against the temperature on an arithmetic scale for each series of experiments at different temperatures, and the equation of best fit computed. These graphs will not be presented here, but the equations are as follows:

Series A-1 (5° C. to 30° C.); $k_T = 0.17125 \times 1.065^{(T-20)}$
Series A-2 (5° C. to 20° C.); $k_T = 0.27618 \times 1.096^{(T-20)}$
Series A-3 (5° C. to 20° C.); $k_T = 0.3007 \times 1.092^{(T-20)}$
Series A-4 (5° C. to 20° C.); $k_T = 0.2611 \times 1.069^{(T-20)}$
Series B, Bicarb. (12° C. to 20° C.); $k_T = 0.1612 \times 1.0677^{(T-20)}$
Series B, Phos. (12° C. to 20° C.); $k_T = 0.1770 \times 1.0823^{(T-20)}$
Series C, Phos. (12° C. to 20° C.); $k_T = 0.1805 \times 1.080^{(T-20)}$
Series D (5° C. to 30° C.); $k_T = 0.1491 \times 1.059^{(T-20)}$
Series D (10° C. to 35° C.); $k_T = 0.1782 \times 1.0316^{(T-20)}$
Series D (35° C. to 40° C.); $k_T = 0.2842 \times 0.9496^{(T-35)}$
Series E (5° C. to 25° C.); $k_T = 0.1491 \times 0.0785^{(T-20)}$
Series E (5° C. to 15° C.); $k_T = 0.1115 \times 0.1096^{(T-15)}$
Series E (15° C. to 30° C.); $k_T = 0.1551 \times 1.519^{(T-20)}$
Series E (30° C. to 40° C.); $k_T = 0.2525 \times 0.9747^{(T-30)}$
Series F (10° C. to 25° C.); $k_T = 0.2283 \times 1.065^{(T-20)}$
Series F (30° C. to 40° C.); $k_T = 0.2746 \times 0.9542^{(T-30)}$

It should be noted that in Series D, E and F, two or more formulations were computed. These formulations take into consideration apparent changes in the value of θ at different temperatures. The value of θ varies considerably for the individual series formulations, and in some cases the values of k at each temperature do not fit well to the formulation.

When the k values of Series A1, D, E and F (bicarbonate water-sewage mixtures) are plotted in Figure 10, and when the arithmetic averages of these k values at each temperature are plotted in Figure 11, there appears to be a change in the value of θ at approximately 15° C. and 30° C.

The solid lines in Figure 10 show the formulations fitted by least squares for 5° to 15° C., 15° to 30° C., and 30° to 40° C., for k values of the bicarbonate dilution water experiments of Series A1, D, E, and F, except for the 5° C. k of series F. The dotted line shows the formulation based on the values of k from 5° C. to 25° C.

In Figure 11, where the averages of the k values at each temperature are

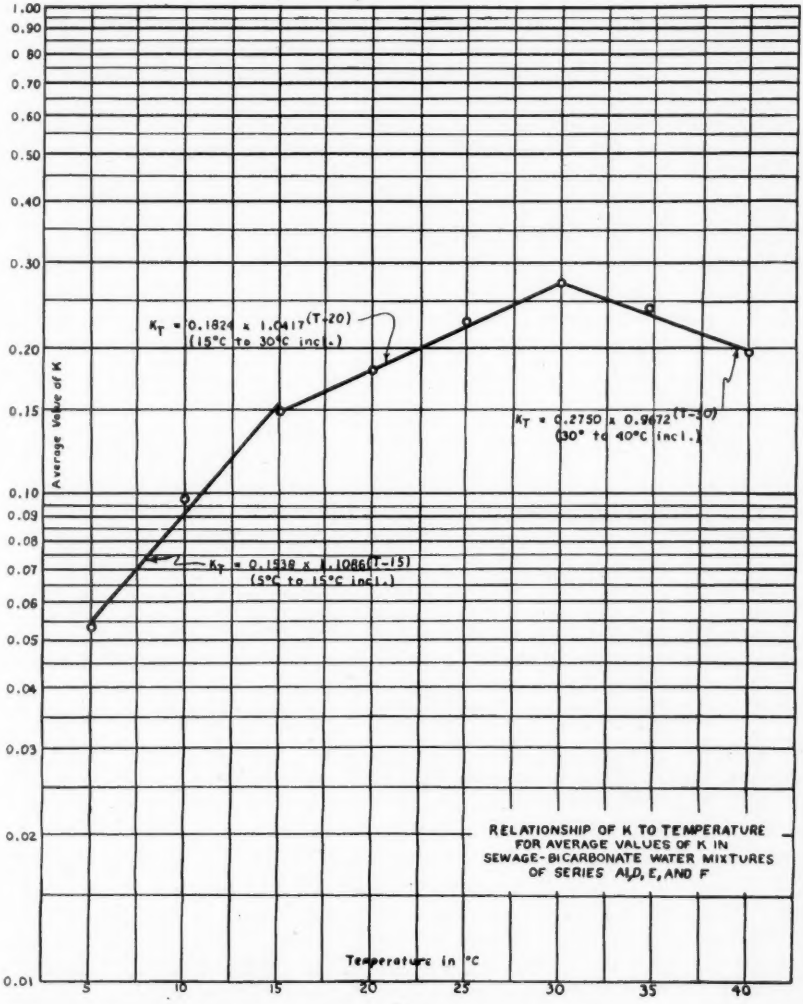

FIGURE 11.—Relationship of k to temperature for average values of k in sewage-bicarbonate water mixtures of Series A1, D, E and F.

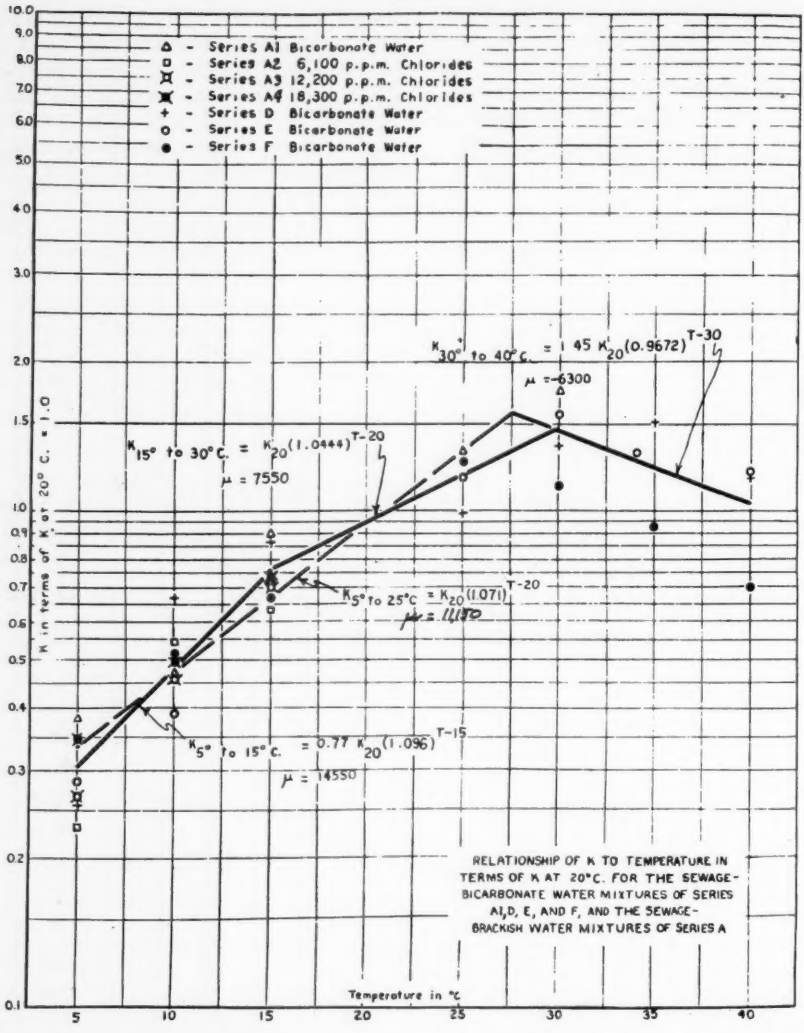
Δ - Series A1 Bicarbonate Water
□ - Series A2 6,100 p.p.m. Chlorides
⊠ - Series A3 12,200 p.p.m. Chlorides
✱ - Series A4 18,300 p.p.m. Chlorides
+ - Series D Bicarbonate Water
o - Series E Bicarbonate Water
● - Series F Bicarbonate Water
K in terms of K at 20° C. = 1.0
Temperature in °C
K30° to 40° C. = 1.45 K20(0.9672)T-30
μ = -6300
K15° to 30° C. = K20(1.0444)T-20
μ = 7550
K5° to 25° C. = K20(1.071)T-20
μ = 11150
K5° to 15° C. = 0.77 K20(1.096)T-15
μ = 14550
RELATIONSHIP OF K TO TEMPERATURE IN TERMS OF K AT 20°C. FOR THE SEWAGE-BICARBONATE WATER MIXTURES OF SERIES A1,D, E, AND F, AND THE SEWAGE-BRACKISH WATER MIXTURES OF SERIES A

FIGURE 12.—Relationship of k to temperature in terms of k at 20° C. for the sewage-bicarbonate water mixtures of Series A1, D, E and F, and the sewage-brackish water mixtures of Series A2, A3, and A4.

plotted, the change in the value of θ at 15° C. and 30° C. is more apparent. Figure 12 shows the values of k at the different temperatures plotted in terms of $k_{20} = 1.0$ for Series A1, D, E, F, and for Series A2, A3 and A4, which were made at the temperatures 5° C., 10°C., 15° C. and 20° C. with a dilution water containing sea water as shown in Table XII. It is seen that the change in the value of θ at about 15° C. is also indicated when the brackish water studies are included.

Figure 13 shows the values of θ, the temperature coefficient and μ, the energy of activation coefficient, for 5°

TABLE XII.—Value of k in Terms of $k_{20} = 1.0$ for Series A1, A2, A3, A4, D, E and F

Temp. (° C.)	Series A1	Series A2	Series A3	Series A4	Series D	Series E	Series F	Average k
	Bicarb. Water	Chlorides 6,100 P.P.M.	Chlorides 12,200 P.P.M.	Chlorides 18,300 P.P.M.	Bicarb. Water	Bicarb. Water	Bicarb. Water	
5	0.382	0.230	0.264	0.347	0.256	0.284	—	0.299
10	0.473	0.547	0.456	0.494	0.670	0.390	0.508	0.505
15	0.900	0.632	0.709	0.736	0.865	0.715	0.667	0.746
20	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000
25	1.336	—	—	—	0.991	1.180	1.257	1.191
30	1.760	—	—	—	1.361	1.567	1.123	1.453
34	—	—	—	—	—	1.313	—	—
35	—	—	—	—	1.518	—	0.925	1.252[1]
40	—	—	—	—	1.170	1.202	0.702	1.025

[1] Average of 34° C. and 35° C. values used at temperature of 34.67° C.

C. differences in temperature based on the average values of k at each temperature for Series A1, D, E and F. The values of μ were computed from the following equation of Van't Hoff-Arrhenius:

$$\log \frac{k_1}{k_2} = \frac{\mu(T_1 - T_2)}{2.3026R(T_1+273)(T_2+273)}$$

where T_1 and T_2 are the respective temperatures and R is the universal gas constant (1.9885 calories). The values of the temperature coefficient θ for 5° C. temperature intervals were computed from the following equation:

$$\frac{k_1}{k_2} = \theta^{(t_1 - t_2)}.$$

The value of μ for 5° C. temperature intervals is largest at 5° C. to 10° C., and in general becomes smaller as the temperature increases, with negative values of μ occurring at 30° C. to 35° C., and 35° C. to 40° C.

Belehradek (19) suggested that the Arrhenius equation does not properly describe the relationship between the velocity of biological reactions and temperature, and that the reaction velocity varies as the temperature in degrees centigrade raised to some power, as shown in Figure 14 for the average values of k of Series A1, D, E and F. The averages of the k values at different temperatures fit very well to this type of formulation, in which the logarithms of k and T plot as a straight line.

The magnitude of k in the temperature range 30° C. to 40° C. is shown to decrease from a maximum value at about 30° C. as the temperature is increased. So far as the author has been able to ascertain, these results are the first to show this phenomenon for aerobic decomposition of sewage. This optimum temperature condition for biological oxidation has been shown by different workers to exist in anaerobic decomposition at about the same temperature. However, for aerobic biochemical oxidation, it has been generally considered that there existed a more or less constant relationship, designated as θ, between the magnitude of k and temperature in the range 2° C. to 40° C., although several workers investigating the activity of yeasts and bacteria have shown that the value of μ decreased with an increase in the temperature above 30° C. Holzmüller (20) studied the germination rate of spores of nine different bacilli at different temperatures, and found the rate to be greatest at about 30° C., and that it decreased as the temperature was increased above 30° C. Since biochemical oxidation is, to a considerable degree, a function of the metabolic activity of bacteria, the

oxidation rate would be expected to be a maximum in the range of optimum temperature for bacteria.

The apparent change in the value of θ at about 15° C. is not as distinct as the change at 30° C. Taken individually, Series F and Series A4 give no indication of this change. The other series indicate it, but because of the general variation in the values of k, a significant change in θ at 15° C. tends to be indistinct. When the average of the k values at the respective temperatures is considered, the change in slope is evident.

The value of θ in the temperature range 5° C. to 25° C. or 30° C. for the individual series varies from about 1.057 to 1.092. The average value of θ in this range is 1.071, as shown in Figure 10. These values are considerably higher than the value of 1.047

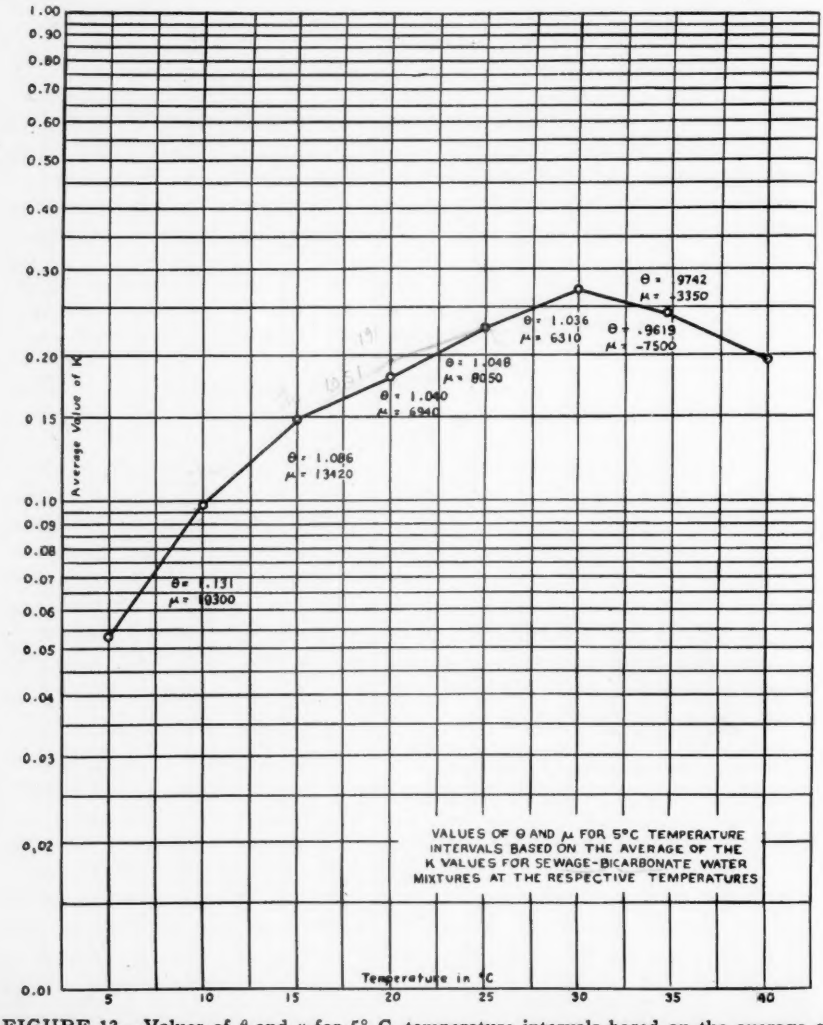
Average Value of K
Temperature in °C
θ = 1.131
μ = 10300
θ = 1.086
μ = 13420
θ = 1.040
μ = 6940
θ = 1.048
μ = 8050
θ = 1.036
μ = 6310
θ = .9742
μ = -3350
θ = .9619
μ = -7500
VALUES OF θ AND μ FOR 5°C TEMPERATURE INTERVALS BASED ON THE AVERAGE OF THE K VALUES FOR SEWAGE-BICARBONATE WATER MIXTURES AT THE RESPECTIVE TEMPERATURES

FIGURE 13.—Values of θ and μ for 5° C. temperature intervals based on the average of the k values for sewage-bicarbonate water mixtures at the respective temperatures.

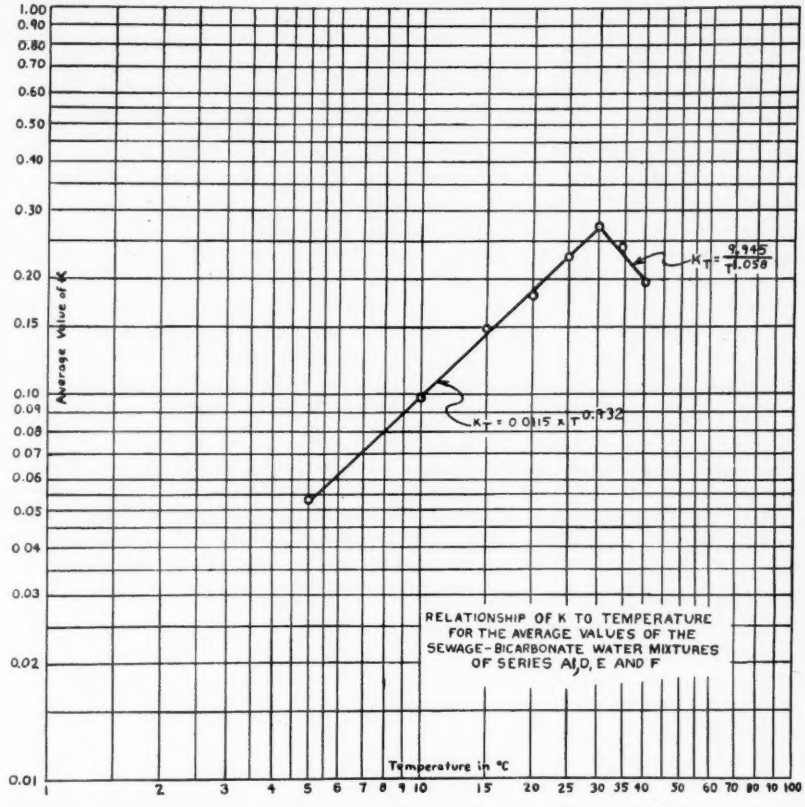
Average Value of K
Temperature in °C
$K_T = 0.0315 \times T^{0.732}$
$K_T = \frac{9.945}{T^{1.058}}$
RELATIONSHIP OF K TO TEMPERATURE FOR THE AVERAGE VALUES OF THE SEWAGE-BICARBONATE WATER MIXTURES OF SERIES A1, D, E AND F

FIGURE 14.—Relationship of k to temperature for the average values of the sewage-bicarbonate water mixtures of Series A1, D, E and F.

found by Streeter and Phelps (18) for sewage incubated at temperatures of 8° C. to 37° C., and confirmed by Theriault (8) in his studies of Ohio River water at 9° C., 20°C. and 30° C. Moore (9), from experiments at 20° C., 18° C., 10° C., 7.5° C., and 5° C., found θ to be 1.065. For the temperature range 0.5° C. to 5° C., he found θ to be 1.145. The author computed a value of θ of 1.123 from Moore's observations in the temperature range 0.5° C. to 10° C. The values in Figures 10, 11 and 12 of 1.108, 1.086, and 1.097 for θ in the temperature range 5° C. to 15° C. approach quite closely the value of 1.123 for Moore's investigations. The values for θ for the temperature range 15° C. to 30° C. of 1.041 and 1.0444 agree quite well with the value of 1.047 of Phelps and Streeter and of Theriault.

The results of Sawyer and Rohlich (21) and Sawyer and Nichols (22) on the effect of temperature on the rate of oxygen utilization by activated sludges at temperatures of 10° C., 15° C., 20° C., and 25° C. indicate a change in the value of θ at about 15° C. The value of θ for the Sawyer and Rohlich (21) results in the temperature range 10° C. to 25° C. is 1.096. In the range 10° C. to 15° C. θ is 1.123, and for 15° C. to 25° C. θ is 1.083. They computed the relationship between the relative activity of acti-

vated sludge and temperature to be $Y = 0.71\ X^{1.54}$, where Y is the relative activity in per cent based on the activity at 25° C. as 100 per cent and X is the temperature in degrees Centigrade. This activity-temperature relationship suggested by Belehradek fits their results very well.

Slator (23) (24), working on alcoholic fermentation and CO_2 production by yeasts, found a value for μ of 30,050 at 5° C. to 10° C. He also found that the value of μ decreased steadily with each 5° C. increase in temperature to 40° C., but the value of μ did not become negative above 30° C.

Stier (25), in studying the effect of temperature on the rate of oxygen utilization by yeasts, found a uniform effect from 3° C. to 15° C.; a second uniform effect from 15° C. to 30° C., and a third effect from 30° C. to 35° C.; that is, a different magnitude of θ and μ was found for each of the three ranges of temperature, and 15° C. and 30° C. were the critical temperatures. Crozier (26), in discussing the influence of temperature on biological activity, suggested that 15° C. is probably a critical temperature which separates two different rates of reaction. He concludes that when

> "the critical temperature thermal increments are calculated for respiratory processes (O_2 consumption, CO_2 production) in various plants and animals, they are characteristically found to be of two or possibly three types; $\mu = 11{,}500$, and 16,100 or 16,700. The first is commonly encountered above 15° C., and the second below that temperature, but these relations may be reversed."

Belehradek's (19) logarithmic relationship between biological activity and temperature satisfactorily describes the results of the author's investigations, the results of Moore (9) on biochemical oxidation of sewage, the observations of Sawyer and Rohlich (21) on activated sludge, and the observations of Slator (23) (24), Steir (25) and other investigators of the effect of temperature on the rates of yeast activity and multiplication of bacteria. However, it does not describe the relationship between k and temperature found by Theriault (8) and Greenfield and Elder (11).

It is possible that the lower value of μ found as the temperature is raised above 30° C. is partially due to considerable nitrification during the first stage at the higher temperatures.

The whole problem of rate of oxidation is so complexly associated with different factors that the limited agreement and consistency found in this investigation and in the investigations of others is believed to be significant. There is a relationship between temperature and the metabolic rate and the rate of multiplication or growth of bacteria. However, the relationship of temperature to biochemical oxidation of sewage is complicated by other factors. First, most biochemical changes are the result of the action of biological catalysts or enzymes. Hence, for a specific organism, if all other factors remain uniform, the rate of biochemical oxidation will depend upon the rate the enzymes are produced and the rate at which they are destroyed. The rate of enzyme production may be related to temperature in three ways: (1) the rate of enzyme production by a single cell may vary with temperature; (2) the oxidizing properties of the enzyme may vary with temperature; and (3) the rate of multiplication of cells will vary with temperature. Secondly, there may be several different kinds of organisms present, which in turn all produce enzymes and themselves multiply at different rates at different temperatures. It is well-known that different organisms have different optimum temperatures for growth, and respond differently to temperature changes. Thirdly, the rate of biochemical oxidation is dependent upon

the material being oxidized in accordance with (1) the chemical characteristics, (2) the availability of the material, and (3) the physical nature, whether in true solution, colloidal solution, or coarsely suspended.

Effect of Temperature on Ultimate First-Stage B.O.D.

Prior to this study there have been two major investigations of the important problem, the effect of temperature on the magnitude of the ultimate first stage of biochemical oxidation: one by Theriault (8) at temperatures of 9° C., 20° C., and 30° C., and another by Moore (9) in which temperatures from 0.5° C. to 20° C. were used.

Theriault (8) deduced the following formulation which has been generally accepted for the effect of temperature on the first stage L:

$$L_T = L_{20}\,[1 + 0.02(T - 20)]$$

where L_T = total ultimate first stage B.O.D. at any temperature T

L_{20} = total ultimate first stage B.O.D. at 20° C.

Table XIII shows the values of the calculated ultimate first stage B.O.D. L (from Tables I to IX), together with the values of L of each series in terms of $L_{20} = 100$.

It is seen that there is not great variation in the ultimate first stage demands at the different temperatures, except for the 5°, 30°, 35° and 40° C. curves of Series F. This is also seen in the plotted curves in Figures 1 to 9. The Series F 30° C., 35° C., and 40° C. observations in Figure 9 show that the usual break between the first and second stage was not apparent at 40° C., and not very pronounced at 30° C. and 35° C. It has been pointed out by different workers that nitrification is often found to start early during the first stage at higher temperatures.

Viehl (27) reported that the rate of oxidation of nitrogenous material was greatly affected by temperature; being increased two or three times for each 10° C. temperature increase. Different workers have found some nitrification starting as early as the third day of incubation. It is possible that larger values for the first-stage demand at higher temperatures is due to considerable nitrification taking place at these temperatures, but not at the lower temperatures.

It may be seen that in some instances, where there is considerable variation between the calculated first-stage demand at the different temperatures, it is due to the course of deoxygenation for those experiments being not exactly unimolecular. Therefore, sometimes the observations toward the end of the first stage are either above or below the computed L, and the observations are often nearer the magnitude of the first-stage demand at other temperatures than is the computed curve.

The computed values for the ultimate first-stage demand in terms of $L_{20} = 100$, as shown in Table XIII, are plotted in Figure 15. After omitting the 5° C., 30° C., 35° C., and 40° C. values of Series F as being erratic, in general the values at the different temperatures fall between 90 and 110, which is an entirely different relationship than the formulation of Theriault.

Using only the points between 5° C. and 25° C., inclusive, and omitting the Series F, 5° C. value, the following equation is derived for L at any temperature in terms of L at 20° C.:

$$L_T = L_{20}\,[1+0.000657(T-20)]$$

The mean and standard deviation for the values used to compute this equation are measures of the tendency for these values to be the same over the temperature range. The mean is 99.7, and the standard deviation, 5.08.

TABLE XIII.—Ultimate First-Stage B.O.D. in Terms of L_{20} = 100

Temp. of Incub. (° C.)	Series A1		Series A2		Series A3		Series A4		Series B		Series D		Series E		Series F		Average in Terms of L_{20} = 100
	Bicarbonate		Chlorides 6,100 P.P.M.		Chlorides 12,200 P.P.M.		Chlorides 18,300 P.P.M.										
	Ultimate 1st-Stage B.O.D. (p.p.m.)	B.O.D. in Terms of L_{20} = 100	Ultimate 1st-Stage B.O.D. (p.p.m.)	B.O.D. in Terms of L_{20} = 100	Ultimate 1st-Stage B.O.D. (p.p.m.)	B.O.D. in Terms of L_{20} = 100	Ultimate 1st-Stage B.O.D. (p.p.m.)	B.O.D. in Terms of L_{20} = 100	Ultimate 1st-Stage B.O.D. (p.p.m.)	B.O.D. in Terms of L_{20} = 100	Ultimate 1st-Stage B.O.D. (p.p.m.)	B.O.D. in Terms of L_{20} = 100	Ultimate 1st-Stage B.O.D. (p.p.m.)	B.O.D. in Terms of L_{20} = 100	Ultimate 1st-Stage B.O.D. (p.p.m.)	B.O.D. in Terms of L_{20} = 100	
5	238	103.5	254	108.0	247	104.5	243	98.4	—	—	233	98.6	236	94.6	104	70.2[2]	98.9
10	238	99.0	263	112.0	235	99.5	241	97.5	—	—	217	91.8	230	92.2	146	98.5	97.8
	—	—	—	—	—	—	—	—	—	—	—	—	(239)	(109.5)	(123)	(84.2)	—
12	—	—	—	—	—	—	—	—	122	88.3	—	—	—	—	—	—	—
	—	—	—	—	—	—	—	—	(133)	(92.2)	—	—	—	—	—	—	—
15	224	97.0	252	107.0	237	100.5	247	100.0	—	—	222	94.0	247	99.0	138	93.2	95.8
20	230	100.0	235	100.0	236	100.0	247	100.0	138	100.0	236	100.0	249	100.0	148	100.0	100.0
	—	—	—	—	—	—	—	—	(144)	(100.0)	—	—	(218)	(100.0)	(146)	(100.0)	—
25	259	112.5	—	—	—	—	—	—	—	—	238	100.9	240	96.2	159	107.5	102.8
30	278	121.0	—	—	—	—	—	—	—	—	267	113.2	242	97.0	210	142.0[2]	110.4
34	—	—	—	—	—	—	—	—	—	—	—	—	257	103.1[1]	—	—	—
35	—	—	—	—	—	—	—	—	—	—	244	103.3	—	—	225	152.0[2]	103.2
40	—	—	—	—	—	—	—	—	—	—	231	97.7	268	107.5	256	173.0[2]	102.6

[1] Averaged with 35° C. results.

[2] Omitted in calculation of average.

( ) Shows phosphate dilution water.

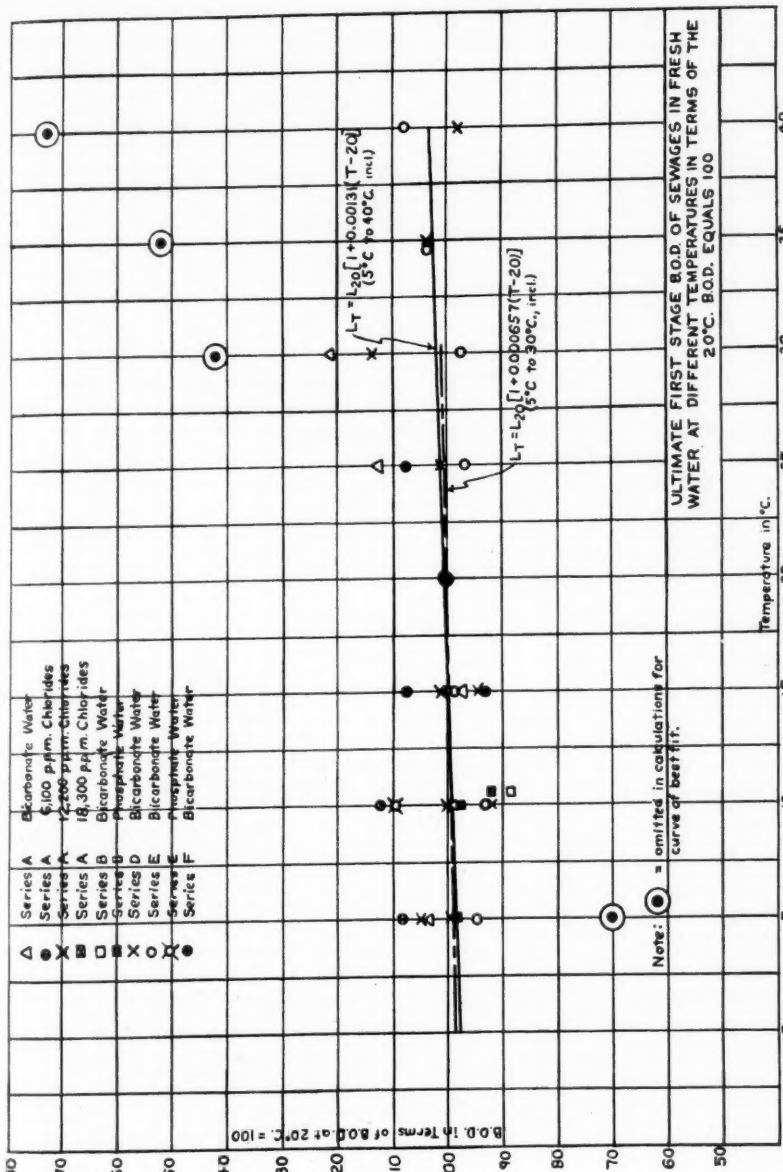

FIGURE 15.—Ultimate first-stage B.O.D. of sewages in fresh water at different temperatures, in terms of $L_{20} = 100$.

If all the points except the 5° C., 30° C., 35° C., and 40° C. values of Series F are analyzed, the equation becomes:

$$L_T = L_{20}\,[1+0.00131(T-20)]$$

The mean and standard deviations in this case are, respectively, 100.25 and 5.33.

Moore (9), at temperatures of 0.5° C. to 20° C., found the constants of the Theriault equation to be 0.206 and 0.0082 for two different sewages.

Different sewages and polluted waters vary widely in their chemical and biological characteristics. However, it seems logical that the ultimate first-stage demand should not vary greatly with temperature. The first-stage demand represents indirectly the food material of a more readily oxidizable type that is available for the bacteria. While the metabolic rate of bacteria is slower at the lower temperatures, it might be expected that if given sufficient time they will use up the food supply.

Buchanan and Fulmer, page 63 (28), show results of Müller concerning total crop yields of various bacteria at temperatures from 0° C. to 30° C. While the results are not entirely consistant, in general, there is not a large difference in the number of bacteria produced at temperatures from 5° C. to 30° C. It does take a much longer time to reach the total yield at the lower temperatures. Waksman and Carey (29) also found that at a lower temperature the total number of bacteria will reach as high or a higher value than at the higher temperature, but a longer time is required. If the first stage represents chiefly the oxidation of carbonaceous material, it might

TABLE XIV.—5-Day B.O.D. in Bicarbonate and Phosphate Waters at Different Temperatures

Temp. of Incub. (° C.)	Series A		Series B		Series D		Series E		Series F		Average 5-Day B.O.D. in Terms of $L_{20}=100$
	5-Day B.O.D. (p.p.m.)	5-Day B.O.D. in Terms of $L_{20}=100$	5-Day B.O.D. (p.p.m.)	5-Day B.O.D. in Terms of $L_{20}=100$	5-Day B.O.D. (p.p.m.)	5-Day B.O.D. in Terms of $L_{20}=100$	5-Day B.O.D. (p.p.m.)	5-Day B.O.D. in Terms of $L_{20}=100$	5-Day B.O.D. (p.p.m.)	5-Day B.O.D. in Terms of $L_{20}=100$	
5	124	62.8	—	—	100	47.5	98	46.0	90	64.3	55.0
10	127	64.4	—	—	165	78.5	117	55.0	110	78.5	69.1
	—	—	—	—	—	—	(132)	(68.6)	(107)	(76.5)	(72.5)
12	—	—	80	69.5	—	—	—	—	—	—	—
	—	—	(86)	(69.3)	—	—	—	—	—	—	—
15	187	95.0	—	—	187	89.0	183	86.0	117	83.5	88.4
20	197	100.0	115	100.0	207	100.0	213	100.0	140	100.0	100.0
	—	—	(124)	(100.0)	—	—	(192)	(100.0)	(140)	(100.0)	(100.0)
25	242	123.0	—	—	212	102.0	215	101.0	155	111.0	109.2
30	265	134.5	—	—	252	121.5	230	108.0	200	143.0	126.7
34	—	—	—	—	—	—	235	110.5[1]	—	—	—
35	—	—	—	—	235	113.5	—	—	210	150.0	124.7
40	—	—	—	—	215	104.0	240	113.0	220	157.0	124.7

( ) Shows phosphate water.

[1] Averaged with 35° C.

be expected that it would be the same for all temperatures.

The results of Greenfield and Elder (11), for diluted sewage incubated at 2° C., 14° C., and 20° C., and at 2° C., 6° C., and 20° C., without being entirely consistent show that the first-stage demand at the lower temperatures was as great as at the higher temperature. Baity's results (13) of long-time B.O.D. observations, on sewage diluted with both fresh water and sea water at 20° C. and 25° C., show practically the same ultimate first-stage at 25° C., as at 20° C.

Relationship of 5-Day B.O.D. to Temperature

The 5-day oxygen demand is a function of the ultimate first-stage demand and the rate of deoxygenation k. Since the ultimate first-stage demand was generally found not to vary widely at temperatures from 5° C. to 30° C., an analysis of 5-day B.O.D. is largely an analysis of the rates of oxidation in terms of 5-day B.O.D. Since 5 days is the standard time of incubation at 20° C. for most B.O.D. determinations, it is believed that the relationship found for the relative magnitudes of the 5-day B.O.D. at different temperatures is of interest.

The biochemical oxygen demand values at a time 5 days after the lag period for the bicarbonate and phosphate water dilutions of sewage of Series A1, B, C, D, E, and F in terms of the 5-day 20° C. B.O.D. equals 100 are shown in Table XIV and plotted in Figure 16. As would be expected, it is seen that the magnitude of the 5-day B.O.D. at temperatures above 30° C., except for Series F, becomes smaller because of the decrease in the magnitude of k. This agrees with Waksman and Renn, (30) who report the following oxygen depletion values after 6 days incubation of sea water: At 2° C., 0.26 ml. per liter; at 12° C., 0.83 ml. per liter; at 22° C., 1.39 ml. per liter; at 34° C., 1.14 ml. per liter. The equation of best fit for the relationship of the observations from 5° C. to 30° C., inclusive, is:

$$L_{T\ (5\text{-day})} = L_{\underset{(5\text{-day})}{20^\circ\text{C.}}} [1 - 0.0283(T - 20)]$$

The values at temperatures above 30° C. cannot be satisfactorily analyzed. It is probable that nitrification starting early at the higher temperatures of 30° C., 35° C. and 40° C. is responsible for the high 5-day B.O.D. values of Series F.

The Lag Period

Biochemical oxygen demand observations often show an initial period of variable length in which oxidation either is not taking place or is taking place at a rate much lower than the normal rate of oxidation following the lag period. Thomas' "slope method" (4) provides for computation of the lag when determining the curve of best fit to the observations. The magnitude of the lag for the different experiments of this investigation is shown in Tables I to IX and in Figures 1 to 9. It is seen that while the lag periods for different series and different temperatures are not strictly comparable, the lag is generally largest at the lowest temperature, (5° C.), and becomes less as the temperature increases until it is very small or negative at temperatures of 20° C. and higher. Negative values for the lag are usually considered to indicate an immediate oxygen demand; however, when small, they may be due to the observations being not exactly unimolecular.

The length of the lag period has been shown by Butterfield and Wattie (31) to be dependent upon the number of bacteria present in the initial mixture, *i.e.*, the amount of seeding. Their findings indicate that up to a certain limit, the greater the number of bacteria present at the start of incubation, the shorter the lag period at any given temperature. Since bacteria multiply more slowly, and probably produce

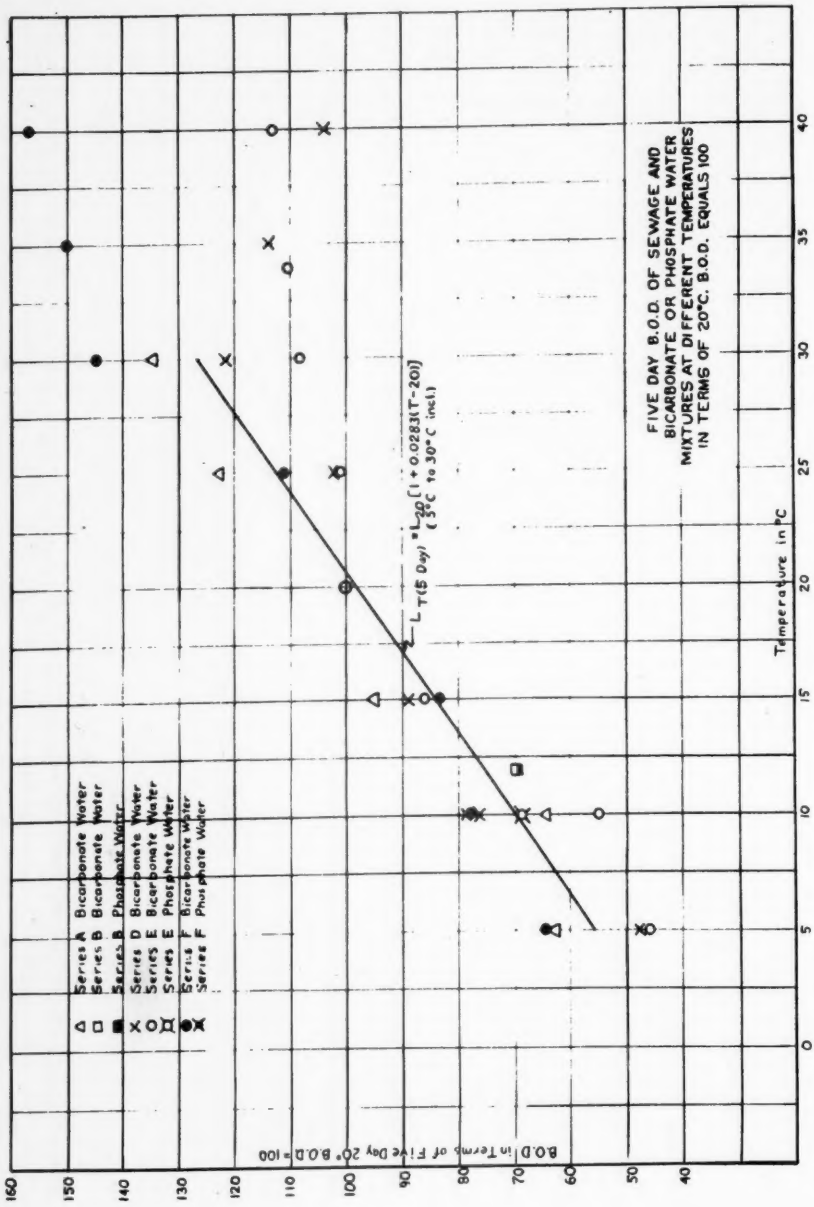

FIGURE 16.—Five-day B.O.D. of sewage and bicarbonate or phosphate water mixtures at different temperatures in terms of 20° C. B.O.D. equals 100.

enzymes more slowly at low temperatures, the lag period is related to temperature, as well as to the number of bacteria present at the start of incubation. Greenfield, Elder and McMurray (32) studied the lag period at 2° C. and found considerable difference in its duration, depending upon whether or not the material was seeded with low-temperature organisms. In studying the development in numbers of bacteria at 2° C., they found slow increase during the first 4 days.

Abbott (14) found a lag period in a substantial percentage of his 20° C. B.O.D. determinations without special seeding. The lag was larger when the value of k was larger and also varied between raw and settled sewage, centrifuged sewage, and river water. He found a much larger lag at 11° C. than at 20° C., and seldom any lag at 25° C. It may be seen from the observations for some of the curves in Figures 1, 7, 8, and 9, that after an initial lag period, oxidation seems to proceed more rapidly than when there is no lag period.

While the lag period is of importance in bottle experiments, and may have considerable effect on the determination of the 5-day B.O.D., it is doubtful that it would be significant in streams, even at low temperatures, because acclimatized seed organisms would be present.

Second or Nitrification Stage at Different Temperatures

While this investigation was intended to cover only the first stage of oxidation at different temperatures, some information concerning the second or nitrification stage was obtained. In several experiments, the constants for the curve of best fit to the observations have been determined. In other experiments, the data were too erratic or too limited to permit computation of the constants. Table XV shows the values of k and L for the curves where the observations were such as to permit a statistical analysis. The approximate time for a pronounced second stage to start is shown.

As an illustration of the inconsistency of second stage observations, the 20° C. experiment Series A1 is the only curve of the series where the observations fit well the computed curve. In Series B, the 20° C. bicarbonate dilution water experiment observations fit the computed curve well, while the observations of the phosphate water experiment at the same temperature and for the same sewage were too scattered to be analyzed mathematically.

The values of k for the second stage, where it was possible to compute them satisfactorily, show little agreement or consistant relationship. The values of the second stage L of series D at temperatures from 15° C. to 35° C. agree very well, but this is not true for the other series.

Thomas (4) reported a value of the second stage k of 0.062 for well-seeded sewage at 20° C., and Moore (9) found 0.063 at 20° C. and 0.071 at 18° C. The Series A1 values at 20° C. and 25° C. are the only values of this study which agree with their results.

The time required to the onset of the second stage is affected greatly by temperature. The experiments at 5° C., covering periods from 43 to 67 days, showed no evidence of a typical second stage. Moore (9) observed the time to establish nitrification at 5° C., to be from 42 to 64 days for sewage and from 56 to 66 days for polluted stream water.

At 10° C., the second stage started in Series D at 45 days and in Series F the second stage started at 60 days for phosphate dilution water, but the bicarbonate water experiment did not show a second stage at 66 days. In Series E, no second stage was noticeable at 55 days at 10° C. It is probable that some nitrification is taking place during the first stage at the lower temperatures, since the B.O.D. gradually rises and may exceed the value of the

TABLE XV.—Data on Nitrification Stage in Bicarbonate and Phosphate Waters

Temp. (° C.)	Series A1			Series B			Series C			Series D			Series E			Series F		
	k	*L* (p.p.m.)	Approx. Time to Establish Second Stage (days)	*k*	*L* (p.p.m.)	Approx. Time to Establish Second Stage (days)	*k*	*L* (p.p.m.)	Approx. Time to Establish Second Stage (days)	*k*	*L* (p.p.m.)	Approx. Time to Establish Second Stage (days)	*k*	*L* (p.p.m.)	Approx. Time to Establish Second Stage (days)	*k*	*L* (p.p.m.)	Approx. Time to Establish Second Stage (days)
5	—	—	>43	—	—	—	—	—	—	—	—	>67	—	—	>45	—	—	>65
10	—	—	>40	—	—	—	—	—	—	*	*	45	—	—	>55	—	—	*
(10)	—	—	—	—	—	—	—	—	—	—	—	—	—	—	(>52)	—	—	(*)
15	0.1121	348	27	—	—	—	—	—	—	0.2016	360	20	0.2479	424	23	0.1540	305	13*
20	0.0679	364	15	0.1131	293	13	*	>480	8	0.1299	376	11	*	*	24	0.0233	452	9
(20)	—	—	—	*	275	18	*	>440	10	(0.1980)	(394)	(12)	(*)	>400*	(17)	(*)	(*)	(9)
25	0.0802	456	11	—	—	—	—	—	—	0.3717	361	9	*	>360*	9	0.0651	334	7
30	*	>440*	10	—	—	—	—	—	—	*	>375*	8	*	>380*	8	0.1118	330	7
34	—	—	—	—	—	—	—	—	—	—	—	—	0.1323	441	6	—	—	—
35	—	—	—	—	—	—	—	—	—	0.3350	366	7	—	—	7	0.4333	330	5
40	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	

( ) Shows phosphate water.
* Indicates that the observed points were too few or too widely scattered to permit statistical analysis.

first stage at higher temperatures without exhibiting a typical second stage. Moore (9) found nitrification at 10° C., starting at about 38 days for two different sewages, using both bicarbonate and phosphate dilution waters, and 23 and 42 days for two different river waters.

At 15° C., a second stage was established in Series A1, D and E at 20 to 27 days, and in Series F, nitrification apparently starts slowly at 12 days and continues at about the same rate to 30 days, when the typical second stage begins.

As the temperature increases, the time to establish nitrification is reduced from about 9 days at 25° C. to 8 days at 30° C. and between 6 and 7 days at 35° C. Stoddard (33) reports that nitrification is most active at 30° C. and falls off both above and below that temperature.

Conclusions

From the results of these experiments on the effect of temperature on biochemical oxidation of sewage, the following recapitulation and conclusions are drawn:

1. The general course of the first stage of biochemical oxidation of diluted sewage conforms closely to the characteristic curve described by the unimolecular equation. The probable errors in k and L are generally small.

2. The magnitudes of the rate of biochemical oxidation k for domestic sewage are larger in the temperature range 5°C. to 30° C. than the usually accepted values of k at those temperatures. The average k at 20° C. of 0.19 of this study is approximately twice the commonly used value of 0.1 found by Phelps (3) and Theriault (8).

3. The magnitude of k for different sewages at any temperature may vary considerably. The variation of k and the lag, when it occurs, make the 5-day B.O.D. not very reliable as a measure of the strength of sewage and wastes.

4. The Van't-Arrhenius equation and the Streeter and Phelps modification describe the relationship between the magnitude of k and temperature in the range 5° C. to 40° C., if three different ranges of uniform temperature effect are considered. The first range from below 5° C. to about 15° C., in which the average value of μ is 16,950 and the average value of θ is 1.108. The second uniform temperature effect is in the range of about 15° C. to about 30° C., for which the average value of μ is 6990 and the value of θ is 1.041. The third uniform temperature effect is from about 30° C. to over 40° C., in which k decreases as the temperature is increased. The average values of μ and θ in this range are -6510 and 0.9657, respectively.

5. The relationship between the oxidation rate, k and the temperature may be closely described by an equation of the form $k_T = aT^b$, where T is temperature in degrees Centigrade and a and b are constants. When this equation is used, there are two temperature ranges in which the temperature effect is uniform; one from below 5° C. to about 30° C., for which the average values of a and b are 0.011 and 0.932, respectively; the other from about 30° C. to over 40° C., for which the average values of a and b are 0.045 and -1.058.

6. The magnitudes of the ultimate first stage of biochemical oxidation of sewage are not affected significantly by the temperature of incubation in the range 5° C. to 30° C., which does not agree with the commonly accepted view that the ultimate first stage B.O.D. changes 2 per cent for each degree change in temperature.

7. At temperatures of about 30° C. and above, there may be considerable nitrification taking place during the apparent first stage of oxidation, which may make the magnitude of the B.O.D. larger in comparison to the first-stage B.O.D. at lower temperatures.

8. In the temperature range below 15° C., the lag period increases as the temperature is lowered. At temperatures of 20° C. and above, the temperature has very little effect on the lag period. The amount of seed bacteria and their acclimatization affect the lag period of the first stage of biochemical oxidation.

9. The second stage of biochemical oxidation is much more erratic in its course than the first stage, and does not seem to have as consistant a relationship to temperature as the first stage of oxidation. The time of onset for the second stage is retarded as the temperature is lowered below 20° C., and may be over 60 to 70 days at 5° C.

Acknowledgment

The research work reported in this paper was done during graduate study in the Harvard University School of Engineering. The author wishes to express credit, appreciation, and thanks to Dean G. M. Fair, under whose direction the research was done. Appreciation is also expressed to Professors H. G. Baity, Edward W. Moore, Charles E. Renn, Harold A. Thomas and M. C. Whipple, for their cooperation and helpful advice on several aspects of the work.

References

1. "Standard Methods for the Examination of Water and Sewage," Eighth Edition, American Public Health Association (1936).
2. Ruchhoft, C. C., Moore, W. A., and Placak, O. R., "Determination of Dissolved Oxygen, Rideal-Stewart and Alsterbery Modifications of the Winkler Method." *Industrial and Engineering Chemistry*, Anal. Ed., **10**, 701 (1938).
3. Phelps, E. B., "The Disinfection of Sewage and Sewage Filter Effluents with a chapter on the Putrescibility and Stability of Sewage Effluents." U. S. Geological Survey Water Supply Paper, No. 229, pp. 74–88 (1909).
4. Thomas, H. A., Jr., "The Slope Method of Evaluating the Constants of the First Stage Biochemical Oxygen Demand Curve." THIS JOURNAL, **9**, 425 (1937).
5. Thomas, H. A., Jr., "Analysis of the Biochemical Oxygen Demand Curve." THIS JOURNAL, **12**, 504 (1940).
6. Reed, R. J., and Theriault, E. J., "The Statistical Treatment of Velocity Data." *Journal of Physical Chemistry*, **35**, pp. 673–689, 950–971 (1931).
7. Fair, G. M., "Log Difference Method of Estimating the Constants of the First Stage Biochemical Oxygen Demand Curve." THIS JOURNAL, **8**, 430 (1936).
8. Theriault, E. J., "The Oxygen Demand of Polluted Waters." Public Health Bulletin No. 173 (1927).
9. Moore, E. W., "Long Time Biochemical Oxygen Demands at Low Temperatures." THIS JOURNAL, **13**, 561 (1941).
10. Mohlman, F. W., Edwards, G. P. and Swope, G., "Technic and Significance of the Biochemical Oxygen Demand Determination." *Industrial Engineering Chemistry*, **20**, 242 (1928).
11. Greenfield, R. E., and Elder, A. L., "The Effect of Temperature on the Rate of Deoxygenation of Diluted Sewage." *Industrial Engineering Chemistry*, **18**, 281 (1926).
12. Adeney, W. E., "The Relative Capacities of Fresh and Sea Water to Bear Pollution within Limits of Fouling." Fifth Report of the Royal Commission of Sewage Disposal, App. VI Addendum, pp. 433–441 (1908).
13. Baity, H. G., "Some Factors Affecting the Aerobic Decomposition of Sewage Sludge Deposits." THIS JOURNAL, **10**, 539 (1938).
14. Abbott, W. E., "Twenty Years Experience with the Dissolved Oxygen Absorption Test in China." *Journal of the Society of Chemical Industry*, **65**, 87 (1946).
15. Committee on Sanitary Engineering, National Research Council, "Sewage Treatment in Military Installations." THIS JOURNAL, **18**, 791–1028 (1946).
16. Ruchhoft, C. C., Placak, O. R., Kachmar, John F., Calbert, C. E., "Variations in B.O.D. Velocity Constants of Sewage Dilutions." Abstracts of Papers, 110th Meeting of American Chemical Society (1946).
17. Thomas, H. A., Jr., "Aerobic Decomposition of Sewage." Unpublished Thesis, Harvard University (1938).
18. Streeter, H. W., and Phelps, E. B., "A Study of the Pollution and Natural Purification of the Ohio River. III.

Factors Concerned in the Phenomena of Oxidation and Reaeration." Public Health Bulletin No. 146 (1925).

19. Belehradek, J., "Temperature Coefficients in Biology." *Biological Reviews*, **5**, 30 (1930).
20. Holzmuller, K., "Die Gruppe des Bacillus mycoides Flugge." *Centbl. Bakt.*, Abt. Z., **23**, 304 (1909).
21. Sawyer, C. N., and Rohlich, G. A., "Activated Sludge Oxidations. IV. The Influence of Temperature upon the Rate of Oxygen Utilization by Activated Sludge." THIS JOURNAL, **11**, 946 (1939).
22. Sawyer, C. N., and Nichols, M. Starr, "Activated Sludge Oxidations. I. Effect of Sludge Concentrations and Temperature upon Oxygen Utilization." THIS JOURNAL, **11**, 51 (1939).
23. Slator, A., "Studies on Fermentation. I. The Chemical Dynamics of Alcoholic Fermentation by Yeast." *Journal of the Chemical Society* (London), **89**, 128 (1906). Cit. by Buchanan and Fulmer (1930).
24. Slator, A., "The Rate of Alcoholic Fermentation." *Journal of the Institute of Brewing*, **17**, 147 (1911). Cit. by Buchanan and Fulmer (1930).
25. Stier, T. J. B., "The Rate of Oxygen Utilization by Yeast as Related to Temperature." *Journal of General Physiology*, **16**, 815 (1933).
26. Crozier, W. J., "On Biological Oxidations as a Function of Temperature." *Journal of General Physiology*, **7**, 189 (1924).
27. Viehl, K., "Über den Einfluss der Temperatur und de Jahreszeit suf die Biologische Abwasserreignigung." *Centr. fur Bacteriologie*, **91**, 14 (1934).
28. Buchanan, R. E., and Fulmer, E. I., "Physiology and Biochemistry of Bacteria. Vol. II. Effects of Environment on Microorganisms." The Williams and Wilkins Co. (1930).
29. Waksman, S. A., and Carey, C. L., "Decomposition of Organic Matter in Sea Water by Bacteria. I. Bacterial Multiplication in Stored Sea Water." *Journal of Bacteriology*, **29**, 531 (1935).
30. Waksman, S. A., and Renn, C. E., "Decomposition of Organic Matter in Sea Water by Bacteria. III. Factors Influencing the Rate of Decomposition." *Biological Bulletin*, **70**, 472 (1936).
31. Butterfield, C. T., and Wattie, Elsie, "Studies of Sewage Purification. VIII. Observations on the Effect of Variations in the Initial Numbers of Bacteria and of the Dispersion of Sludge Flocs on the Course of the Oxidation of Organic Material by Bacteria in Pure Culture." THIS JOURNAL, **10**, 815 (1938).
32. Greenfield, R. E., Elder, A. L., and McMurray, R. E., "Further Studies on the Biochemical Oxygen Demand Test." *Industrial Engineering Chemistry*, **18**, 1276 (1926).
33. Stoddard, F. Wallis, "Nitrification and the Absorption Theory." Report of the Seventh Annual Congress of Applied Chemistry, p. 183 (1909).

MAKE YOUR HOTEL RESERVATIONS FOR THE DETROIT CONVENTION

The Hotel Statler at Detroit, headquarters for the Twenty-First Annual Meeting of the Federation in October, will be able to accommodate most of the out-of-town registrants. Some rooms will also be made available by the Book-Cadillac Hotel, located about three blocks from the Statler.

Requests for room reservations should be addressed directly to the hotel. Note that the technical program will open on Monday morning, October 18, and will close at noon on Thursday, October 21.

WRITE NOW FOR YOUR RESERVATIONS!

DIGESTER CAPACITY REQUIREMENTS *

By R. S. Rankin

Assistant Manager, North American Division, The Dorr Company, New York, N. Y.

The interesting problem of how much sludge a digester of a certain volume can handle has been answered in various ways, but none of them seem to be entirely satisfactory. A new approach to the problem and possibly a more useful solution is presented. Present practice usually shows that the designing engineer uses one yardstick to establish the size, but when the operator takes over, he seldom knows anything about the yardstick or else he is so engrossed in the real job of disposing of the solids that he never has time to use it.

For many years engineers have determined volume requirements of digesters on the basis of an allowance of so many cubic feet per capita of contributing population. This method was probably introduced with the Imhoff tank and, if so, has been extant for some 35 years. It has proved generally satisfactory for the small plant treating solely domestic sewage, particularly when a liberal factor of safety was included. But where industrial wastes are combined with the domestic sewage, an equivalent population had to be added to the actual human population to allow for this additional load. Where industrial contribution is large in proportion to domestic, this method is only as reliable as is the factor selected for the equivalent population. With the increased industrial discharges to sewer systems in the past 10 years, this method of determination of capacity has not proved adequate.

More recently some engineers have used as their yardstick for determining capacity the pounds of dry solids per month per cubic foot. The weight has been determined either from suspended solids removal or by sampling the sludge going to the digester. While this attempts to recognize the importance of industrial loads, it does not take into account variations in the water content of the sludge, which is ten to twenty times the volume of the solids. The method also does not recognize the fact that all sewage solids do not behave alike. As will be shown later, this yardstick appears to be unreliable unless perchance an oversize digester results. Under such a condition, however, one might select any factor and conclude it to be satisfactory.

The Final Report of the Committee on Sludge Digestion of the ASCE Sanitary Engineering Division, published in the 1938 ASCE *Transactions*, has this to say about tank capacity computations:

"A better basis of design (than cubic feet per capita) is the weight of solids in the sludge removed daily. Consideration must also be given to the percentage of volatile matter in the solids, percentage digested, and, most important of all, the water content of the sludge."

This seems eminently sound advice today, if it can be applied. True, this report continues with the development of formulae for application to a variety of conditions which are intended to take into account all the variables. But the very nature of the formulae would be frightening to most opera-

* Presented at the Twenty-First Annual Meeting of the Pennsylvania Sewage and Industrial Wastes Association, State College, Pa., August 26, 1947.

tors, while the designing engineer who undertakes to use them probably will decide he does not have sufficient confidence in the values he assigns to the variables to trust his results.

Scope of Study

In an endeavor to explore this subject further to see if a yardstick of real value could be found, a study of annual operation records of nearly fifty digester installations was made. In many examples, records for several years were studied. These records were contained mainly in annual reports, generally available to the public, although the circulation of some is quite limited. Some of these reports have been abstracted in THIS JOURNAL in recent years. It was decided that each record to merit study had to be from a plant in operation long enough—generally two or more years—to have acquired a settled operating routine.

Data from these reports were tabulated and computations made to show the relation to volume and also to tank area of a large number of factors, including:

1. Total dry solids added per cubic foot per month.
2. Volatile solids added per cubic foot per month.
3. Undigested solids (or solids remaining), both dry and wet, in cubic feet per month.
4. Digested solids, both dry and wet, per cubic foot per month.
5. Gas production in cubic feet per day per square foot of tank area.
6. Raw sludge added in cubic feet per month.
7. Solids additions, both total and volatile, versus volatile matter reduction.

Input-Output Balance

Most of the studies were limited to about twenty representative plants selected from the complete list, mainly because some basic information was missing from the others. At one stage only those digesters handling primary sludge were considered. Finally, in one series of computations which involved a comparison of the weight of gas produced to the weight of volatile matter destroyed in a unit of time, it was observed that certain plants showed a fairly uniform ratio while others had widely variable ratios. It seemed apparent that this ratio must be almost constant. Consequently this led to the suspicion that some of the records were not completely balanced, or in other words, the products leaving the digester did not equal those entering.

It is well known that for every pound of raw solids added, some 50 or 60 per cent should be removed as digested sludge where long-term operation is considered. But, according to the reports, some of the plants were removing in a year's time only a small fraction of the digested sludge which their analytical data indicated should be removed. Some plants were, of course, discharging large volumes of supernatant solids which had not been considered in any way.

A critical review of all of these operating data disclosed a few plants with a record of output of solids approximately equal to the input on a weight basis. In determining the output of solids, it was necessary to include not only those in the digested sludge, but also those represented by the weight of gas produced and those in the supernatant. In some plants where the supernatant was low in solids, the weight in the supernatant could be neglected without affecting the overall result.

The operating data were again examined to select those records which showed a fairly close relationship between input and output. This resulted in discarding the records from all but a dozen or so plants. It happened that these remaining plants

were representative of various types of treatment processes, they were skillfully operated, and the data were known to be carefully compiled.

There is no implication, intended or otherwise, but those plants whose records failed to measure up to this requirement were not well operated. It is known that unavoidable errors in sampling and variations in analytical technique in many plants introduce so many variables that uniformity of results is very difficult of attainment.

Some may even think that it is impossible to obtain a balance between the products taken out of a digester with those introduced into it. All that can be said is that certain well-seasoned plants do report an approximate balance when results over a minimum period of one year are considered.

It should be added that many of these data are pre-war in origin, when plant operation was undisturbed by war industries and by the dislocation of operating personnel. Since the war, so many plants have experienced abnormal conditions due to excessive overloads, new personnel, etc., that their performance is not up to the best pre-war standard. Hence, the use of pre-war data in part seems fully justified to bring out the salient points. Possibly some postwar data might now be included if it were available.

Adjustment of Data

In some of the plants slight adjustments to the recorded values were made. These were principally in raw sludge volumes, which are recognized as being the most difficult to determine accurately. The adjustments do not exceed a maximum of 15 per cent of the total solids; they average less than 5 per cent. They could have been omitted without affecting general results, but were made more to obtain a mathematically accurate balance than anything else.

The principal generally followed in making adjustments was to assume the wholly metered gas production as correct, and that the weight of volatile matter destroyed should equal the weight of the gas. It was also assumed that the analysis of the digested sludge, both for volatile matter and moisture content, was more likely to be correct than the same analysis for the raw sludge. In most of the plants selected these values were fairly constant from year to year, and could be used with confidence. In determining the volume or amount of sludge solids handled at each plant, those plants which had vacuum filters with weighing devices offered a fairly accurate check on the total pounds of solids processed. Some plants, Buffalo and Cleveland Westerly for example, showed in their annual reports a solids balance which, with the moisture contents given, was readily converted to volumes. In all cases those which could not be readily balanced, even with some slight adjustment, were simply discarded.

No attempt was made to check the dry solids removed as sludge with the suspended solids removal. Most digestion plants return supernatant to the raw sewage, but the solids content of the supernatant is seldom, if ever, reported as an increase in plant influent suspended matter. As a result suspended solids removal determinations are not a true index of solids removed from the clarifier and put into the digester. Where long digestion periods are found, and supernatant is consequently low in solids, this would make little difference; but as the digestion period becomes shorter the supernatant usually becomes heavier in solids, which are recycled from clarifier to digester and back again. In one instance 30 per cent more solids than indicated by the suspended solids removal were being pumped into the digester due to a heavy supernatant recycling.

Gas production has been reduced to its equivalent weight of volatile mat-

TABLE I.—Digester Loadings from Selected Plants Having Output Equal to Input after Adjustments

TABLE I.—Digester Loadings from Selected Plants Having Output Equal to Input after Adjustments

Ref. No.		Source of Raw Sludge	Digester Capacity (cu.ft.)	Ave. Wet Feed Per Month		Detention (days)	Ave. Dry Feed Per Month		Loading (lb./cu.ft./mon.)		Volatile Matter (%)		Reduction by Digestion (%)		Solids (%)	
				Gallons	Cu.Ft.		Total Solids (lb.)	Vol. Matter (lb.)	Tot. Sol.	Vol. M.	Raw	Dig.	Vol. M.	Tot. Sol.	Raw	Dig.
1	Buffalo, N. Y.	Prim. Sed.	750,000	6,550,000	875,000	26	4,704,000	2,982,600	6.3	4.0	63.5	51.6	39.2	24.9	8.6	8.8
2	Sheboygan, Wis.	Prim. Sed.	124,400	802,000	107,000	35	472,980	300,900	3.8	2.4	63.7	49.2	44.5	28.3	7.1	10.1
3	Jackson, Mich.	Prim.; Act. Sl.	172,000	625,000	83,400	62	369,820	234,500	2.1	1.4	63.5	44.5	52.8	33.6	7.1	6.7
4	Akron, Ohio	Imh. Tk. Prim.	146,000	653,000	87,200	50	447,595	291,500	3.1	2.0	65.4	47.4	52.3	34.0	8.1	9.6
5	Peoria, Ill.	Prim.; Act. Sl.	492,000	4,180,000	557,000	27	1,575,000	1,117,000	3.2	2.3	71.0	55.0	49.7	35.2	4.5	4.5
6	Cleveland (Westerly)	Imh. Tk. Prim.	276,000	1,586,500	212,000	39	1,094,000	740,500	4.0	2.7	67.8	49.8	52.4	35.5	8.1	7.5
7	Galesburg, Ill.	Prim.; Trick F.	62,700	197,000	26,200	72	132,512	83,488	2.1	1.3	63.0	42.3	56.8	35.8	7.9	7.7
9	Grand Rapids, Mich.	Prim. Sed.	384,800	1,640,000	218,000	53	676,000	458,000	1.8	1.2	67.7	47.3	55.2	37.6	4.9	12.9
10	Aurora, Ill.	Prim. Sed.	41,250	548,000	73,000	17	157,980	88,000	3.8	2.1	69.5	55.7	44.2	30.8	4.9	3.4
11	Winnipeg, Man.	Prim. Sed.	294,000	1,206,000	161,000	55	969,000	655,000	3.3	2.2	67.7	47.8	56.0	37.8	9.4	6.9
12	Mansfield, Ohio	Prim.; Act. Sl.	78,600	503,000	67,300	35	226,000	177,700	2.9	2.3	78.4	58.0	62.7	49.3	4.7	2.7
13	Battle Creek, Mich.	Prim. Sed.	36,100	724,567	96,500	11	362,000	312,500	10.0	8.6	86.3	73.8	55.3	47.8	5.5	3.1
14	Massillon, Ohio	Chem. Prec.	90,000	360,000	48,000	56	147,000	116,400	1.6	1.3	79.2	50.2	73.0	57.8	4.7	5.1

Ref. No.

1. Buffalo, N. Y., data from 1941–42 Annual Report, pp. 20–26. Raw sludge weight and volume increased 4 per cent to equal "out" products from digesters.
2. Sheboygan, Wis., data for 1939. Raw sludge solids increased 10 per cent to balance.
3. Jackson, Mich., data for 1939 from private communication. Raw solids adjusted upward about 8 per cent.
4. Akron, Ohio, data for 1939 from private communication. Raw solids adjusted downward 12 per cent.
5. Peoria, Ill., data for 1939 from private communication. Three digesters assumed to receive load. No adjustment.
6. Cleveland, Ohio (Westerly), data from 1940 Annual Report, pp. 28–31. Raw sludge solids adjusted 13 per cent upward to equal "out" products from digesters.
7. Galesburg, Ill., data from 1942 Annual Report. No adjustment.
9. Grand Rapids, Mich. Refer "Std. Practice in Separate Sludge Digestion." Final Report of ASCE Committee, 1938 *Trans.*, p. 1720. Data for 15 months. Raw solids increased 0.8 per cent to equal "out" products.

Ref. No.

10. Aurora, Ill. Data from 1942 Annual Report, p. 42. First-stage digestion only considered. This unit receives primary sludge only. Raw sludge volume and total solids assumed to be correct because of accurate meters and methods used. Also volatile matter in digested sludge and weight of gas (15.3 cu. ft./lb.) is assumed correct. Remaining values have been adjusted to these factors.
11. Winnipeg, Man. Data from 1943 Annual Report. Digester feeds as given on pp. 13–16 weighted to allow for units out of service. Digested sludge quantities computed from ash in raw sludge and from percentages volatile matter and solids in digested sludge.
12. Manfield, Ohio; 1939 Report. Raw sludge volume, digested solids and gas assumed as correct, and balance adjusted accordingly.
13. Battle Creek, Mich. Data from 1943 Annual Report, pp. 41–43. First stage only considered. Digester volume of 36,100 cu. ft. computed from tank dimensions.
14. Massillon, Ohio. Data from THIS JOURNAL. Raw sludge solids increased 6 per cent to equal "out" products. Volume of supernatant and per cent solids computed from assumed weight of solids.

ter by using factors of from 14.5 to 15.5 cu. ft. of gas per pound. In some reports a factor was stated, but otherwise 14.5 cu. ft. of gas was assumed as equivalent to one pound of volatile matter. It is known that some authorities claim higher factors up to 15 or 16.5 cu. ft. per lb., for theoretical reasons, and also that some plants report a much higher factor, but the evidence from the plants studied seems to justify the factors used.

Discussion of Data

Table I shows the list of selected plants and the summary of data pertaining to each. Complete figures for each plant showing detailed computations of solids and liquid, together with adjustments, are not included here because they would require excessive space.

With this compilation of data on balanced digester operation, it should be possible to discover some relation between loading, performance and volume. Accordingly, these were plotted first to show, for all types of sludges, the relation between total dry solids in pounds per cubic foot per month and volatile matter reduction, and the same using volatile dry solids instead of total solids. Volatile matter reduction is considered the most suitable available index of performance, as it is a direct measure of the progress of digestion.

The resulting curves are shown in Figures 1 and 2 respectively. A careful study of these two diagrams does not disclose any fundamental conclusion which takes into account all the data plotted. As a matter of fact, no intelligible relationship between dry solids and any other factors which would be useful or applicable can be discovered. Possibly there is no reason why there should be. Dry solids as such do not exist in a digester, since all bacterial digestion takes place only after liquefaction of the particle undergoing digestion. Such particles, moreover, have a high percentage of water in their physical makeup and have no way to exert any influence upon capacity except in their watery condition. Therefore, it seems pertinent to explore the possibility of any relation which might exist between wet sludge volumes, performance, and capacity requirements.

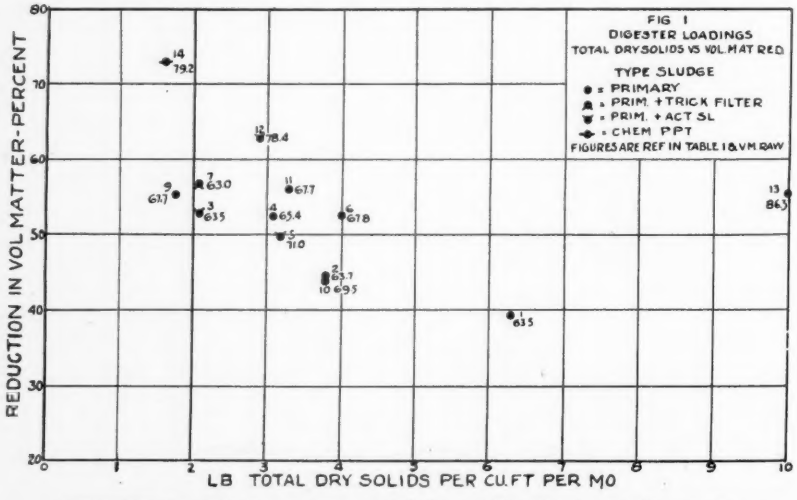

FIGURE 1.—Relation between total dry solids digester loading and volatile matter reduction.

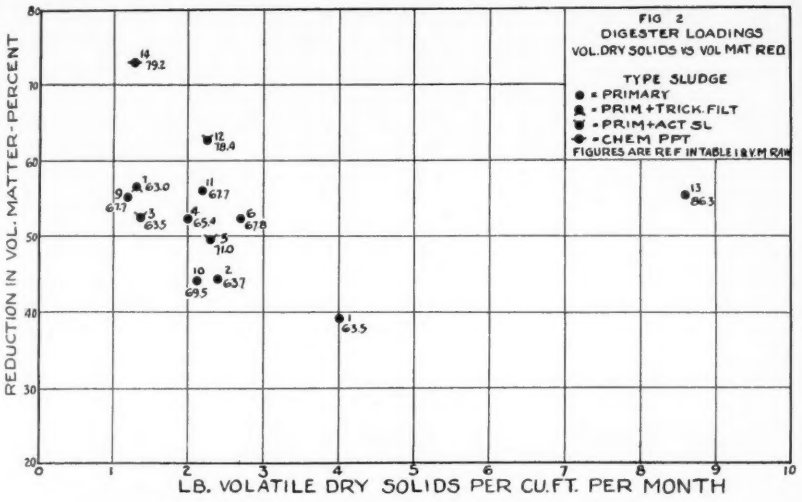

FIGURE 2.—Relation between volatile dry solids digester loading and volatile matter reduction.

Detentions Based on Wet Sludge Volumes

With this object, the detention in the various digesters has been computed on the basis of digester volume divided by the average monthly volume of raw sludge feed. This computation gives the actual theoretical liquid displacement time in the digester, which would seem to hold true regardless of whether the sludge is withdrawn from the supernatant or the digested sludge outlet, or both combined as is usually the case. If the detention in days thus computed be related to performance as measured by volatile matter reduction, the results are as shown in Figure 3. Opposite each point on the diagram is a reference number and the percentage of volatile matter in the raw sludge feed.

It now appears possible to make something out of these figures. Sloping lines representing equal volatile matter percentages in the raw sludge can be interpolated as shown. In addition to the data on plants listed in Table I, information on a few additional plants listed in Table II has been included. The sloping lines have been confined to the period between 15

TABLE II.—Digester Loadings from Selected Plants, Based on Yearly Averages

Only Input Data Considered; Output Not Balanced

Ref. No.	City	Source of Raw Sludge	Digester Capacity (gal.)	Ave. Wet Feed per Month (gal.)	Det. (days)	Vol. Matter (%)		Red. by Dig. (%)		Solids (%)	
						Raw	Dig.	Vol. Mat.	Tot. Sol.	Raw	Dig.
20	San. Dist. Chgo. (Special Tests)	Prim. Sed.	390,000	312,000	37	64.7	50.7	44.1	28.5	3.7	3.7
21	Yakima, Wash.	Prim. Sed.	481,000	215,000	67	74.3	46.7	69.8	51.8	8.3	9.7
22	Janesville, Wis.	Prim. + Act.	512,000	237,000	65	71.9	48.0	63.9	45.9	4.8	10.1
23	Lansing, Mich.	Prim. + Garb.	2,200,000	2,250,000	29	61.5	50.2	37.0	22.8	6.7	8.9

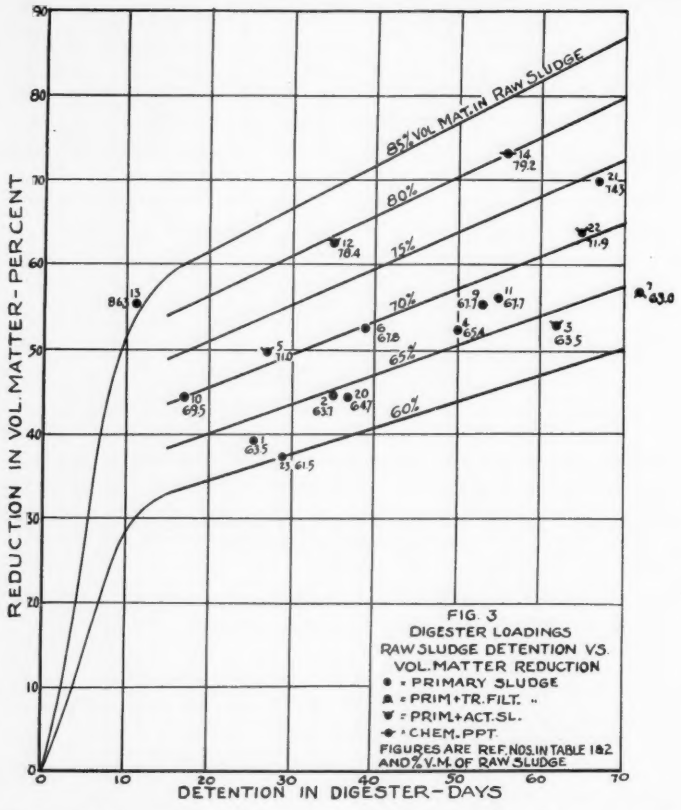

FIGURE 3.—Relation between raw sludge detention and volatile matter reduction.

and 70 days, as sufficient data outside these time intervals has not been obtained. It is possible that these sloping lines should be curved and asymptotic in character.

It is interesting to observe that there is no significant difference in the relation of detention and volatile matter reduction between sludges from different processes, whether primary sedimentation, trickling filter, or activated sludge. Perhaps this is as it ought to be, because under equal temperature conditions, the digestible particles of sludge should be hydrolized and assimilated by the bacteria at the same rate regardless of the origin of the particle. Even though some reduction in the organic matter content of the solids has taken place due to oxidation in treatment processes such as trickling filter or activated sludge, this has been taken into account, because the measure of digestibility used is the volatile matter of the sludge entering the digester as determined by actual laboratory analysis.

Differences which do appear can be caused by many factors such as temperature, volume occupied by scum, intervals between feeding and withdrawal, accuracy of basic data, and possible unknown factors. However, the fact that such a close relationship appears to exist at all is of interest.

It might be argued that this representation disregards variations in intervals between sludge withdrawals,

or that it does not adequately take into account the actual time required for the passage of the sludge solids through the digester. Considering the first point, it should be emphasized that the data for each plant are monthly averages from continuously operating plants, taken over a minimum period of one year, and variations in intervals between withdrawals should be compensating in their effect. Doubtless, some individual months, if used, would be out of line. Concerning the second point, if the dry solids aspect is discarded and the wet sludge idea is accepted, then the probable time of passage through the digester, after the initial period of 10 to 15 days, is a function of time of displacement.

Digester Performance Charts

Assuming that this relationship between detention of raw sludge feed and volatile matter reduction is correct, then digester performance may be readily predicted by the designing

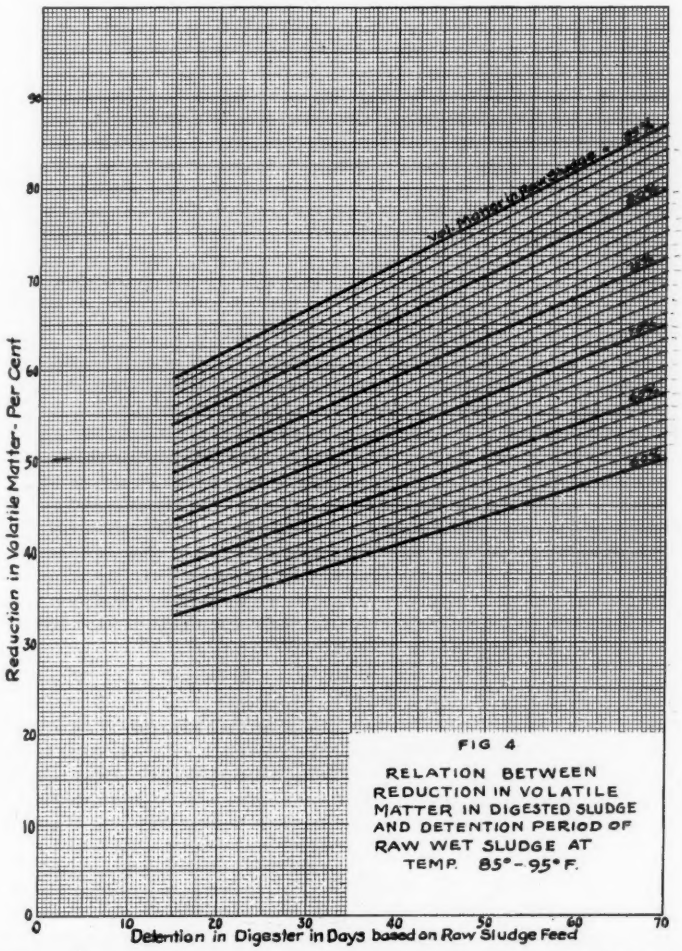

FIGURE 4.—Relation between volatile matter reduction and wet sludge detention at 85°–95° F.

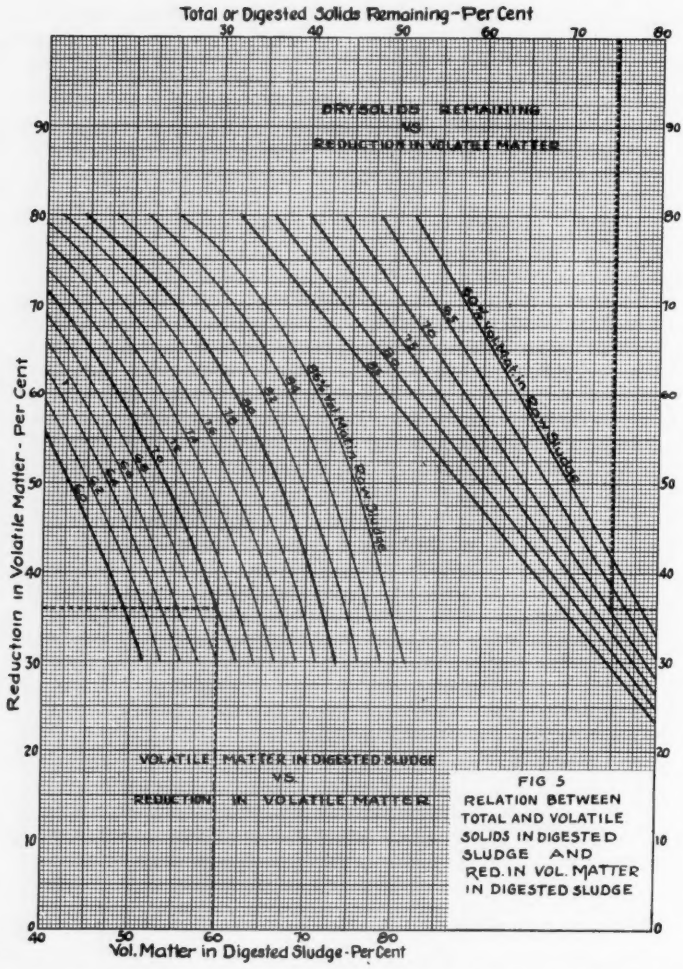
Total or Digested Solids Remaining - Per Cent
DRY SOLIDS REMAINING VS. REDUCTION IN VOLATILE MATTER
Reduction in Volatile Matter - Per Cent
VOLATILE MATTER IN DIGESTED SLUDGE VS. REDUCTION IN VOLATILE MATTER
FIG 5
RELATION BETWEEN TOTAL AND VOLATILE SOLIDS IN DIGESTED SLUDGE AND RED. IN VOL. MATTER IN DIGESTED SLUDGE
Vol. Matter in Digested Sludge - Per Cent

FIGURE 5.—Relation between total and volatile solids in digested sludge and reduction in volatile matter.

engineer and checked by the plant operator with reasonable accuracy and assurance of results. From the basic information shown on Figure 3, a chart for general application has been prepared (Figure 4), and from these data it is possible to compute other useful information such as the solids remaining after digestion and their volatile content, the volume of gas production, and the capacity requirements of digesters from various solids contents of the raw sludge. This information is shown graphically in Figures 5, 6, and 7. The charts should be useful, for example, to an operator who desires to know whether he is removing the correct amount of digested solids.

A word of explanation concerning these diagrams is in order. It will be observed that both Figure 5 and Figure 6 have the common ordinate "Reduction in Volatile Matter," the same

as in Figure 3 and Figure 4. The points for the left-hand curves in Figure 5 were computed by the well-known formula using various selected values:

$$\text{Vol. Matter Reduction} = 1 - \frac{\text{Ash in Raw}}{\text{Ash in Dig.}} \times \frac{\text{Vol. Mat. in Dig.}}{\text{Vol. Mat. in Raw}}.$$

Values are expressed as decimal fractions in the formula, then converted to percentages and tabulated. When enough had been computed, the curves were readily drawn. The same procedure was followed in the curves at the right in Figure 5, using the formula:

$$\text{Total Solids Remaining} = 1 - (\text{Vol. Mat. Red.} \times \text{Vol. Mat. Raw})$$

Again, decimal fractions were used and converted to percentages. These formulas become difficult to memorize and errors are more likely to occur when the percentage factor 100 appears

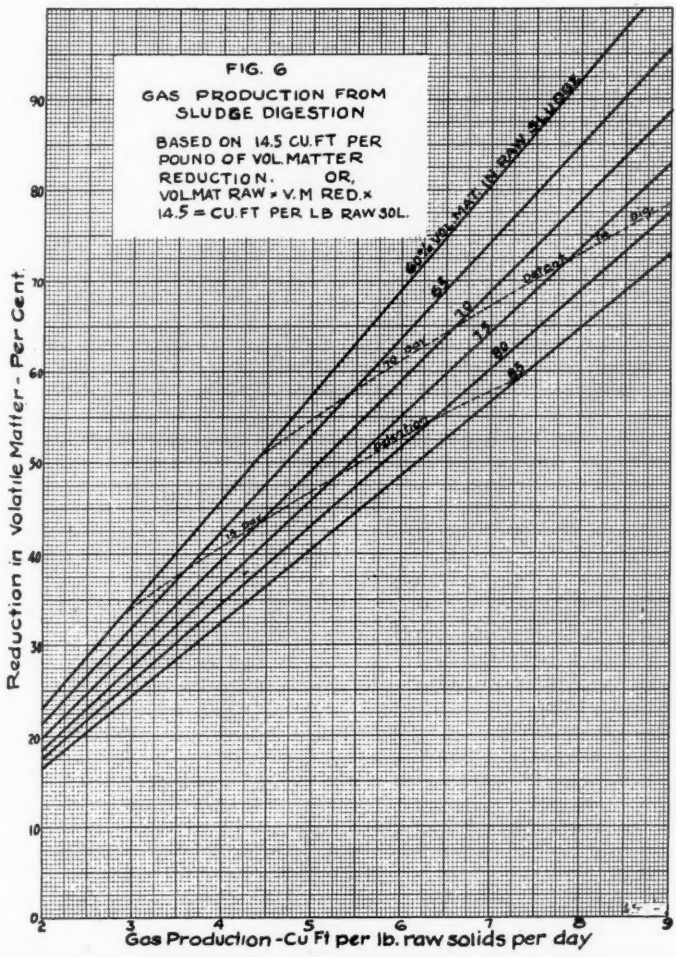

FIGURE 6.—Gas production from sludge digestion.

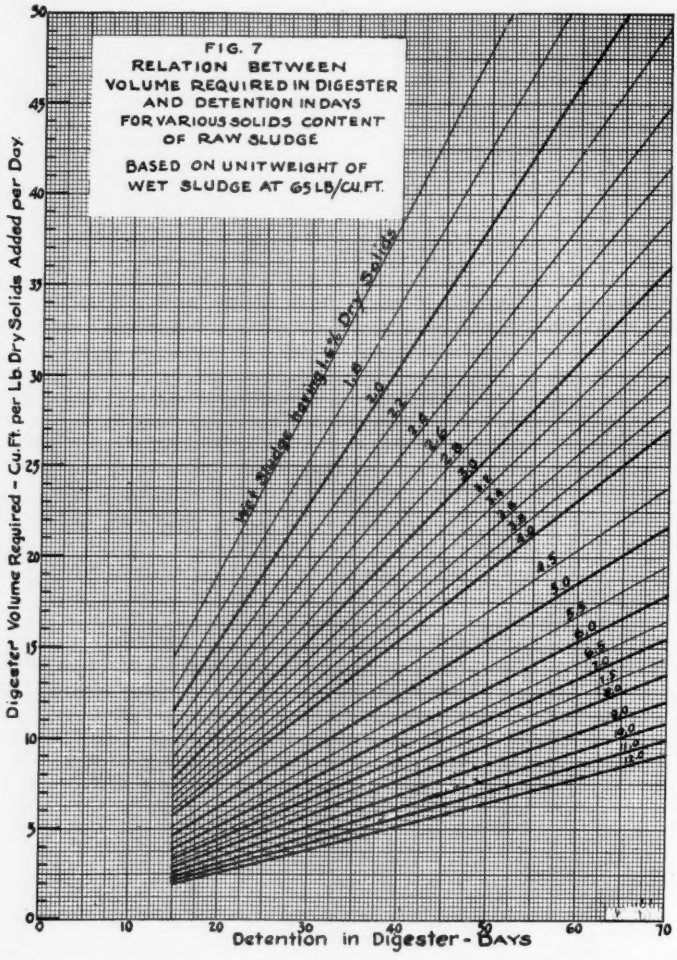

FIGURE 7.—Relation between required digester volume and detention period at various raw sludge solids concentrations.

too frequently, and the author has found it much easier to perform all calculations with decimal fractions and convert only the final product or answer to percentage.

Figure 6 again is a graphic representation of a series of computations of the formula:

Gas Production (in cu. ft. per lb. of raw solids added per day) = Vol. Mat. Raw × Vol. Mat. Reduction × 14.5

Here, it is assumed as discussed previously that one pound of volatile matter destroyed produces 14.5 cu. ft. of gas.

Figure 7 is a line diagram showing volume of digester required for certain assumed charging rates of dry solids having various moisture contents. It will be noted that the unit weight of sludge is assumed as 65 lb. per cu. ft., which is probably nearer the actual than is the customary unit weight of

water (62.5 lb.), but no one will err seriously by continuing to use the latter figure.

It was observed in studying the operating data that plants having detention periods of less than 30 days total were experiencing supernatant troubles, while those with 60 days or over seemed to have no troubles. Between these two intervals the data are inconclusive.

At any rate, it seems evident that ample digestion capacity is one way to obtain freedom from supernatant problems. One other observation is that, as a sludge thickening device, a digester is not too satisfactory, at least in the shorter detention periods. Any appreciable thickening produced in the digester seems to be at the expense of the quality of the supernatant, which leads to the conclusion that the best place to thicken sludge is ahead of the digester, preferably in the primary sedimentation tanks.

One other interesting point might be noted. If it is assumed that the moisture content of the digested sludge is equal to that in the raw sludge, then the weight of the supernatant or excess liquor will be equivalent to that given up by the digested solids. For example, in a plant where the raw and digested solids are both 95 per cent moisture and gas production is, say 10,000 cu. ft. per day or 690 lb., then the theoretical volume of "free" liquor originally attached to the digested solids equals 690 lb. or 83 gal. per day.

Obviously, the data upon which the foregoing conclusions have been drawn are not as extensive as they might be. It is hoped, however, that operators and engineers will find this proposed solution of sufficient interest to apply it to their problems, and in so doing either confirm it, or else discover some other more useful approach to this important subject.

Summary and Conclusions

1. According to annual reports of operation, some digesters are operated to produce a close balance between input and output of solids while the substantial majority do not.

2. The dry solids method of computing digester loading and performance does not appear sound, when studied in connection with plants with balanced input and output.

3. The volume of raw sludge feed and its detention in the digester seem to bear a close relation to performance as measured by volatile matter reduction. This appears true regardless of type of sludge.

4. The raw sludge detention method of evaluating digester performance offers a common yardstick for the designing engineer and operator alike.

5. Long detentions in digesters give most freedom from supernatant troubles.

SOME BACTERIOLOGICAL ASPECTS OF HYDROGEN SULFIDE PRODUCTION FROM SEWAGE*

By H. Heukelekian

Associate Research Specialist, Department of Sanitation, Rutgers University, New Brunswick, N. J.

Sulfides originate in sewage from the reduction of sulfates. This reaction takes place under the influence of a restricted group of organisms which are capable, in the absence of dissolved oxygen, of utilizing the oxygen in sulfates for the oxidation of the organic matter. That is, sulfates serve as hydrogen acceptors in the dehydrogenation of organic matter.

The result of this coupled reaction is the oxidation or dehydrogenation of organic matter, and the reduction or hydrogenation of sulfates to sulfides. This reaction takes place when the other hydrogen acceptors, such as oxygen and nitrates, are eliminated or absent. In the presence of all three hydrogen acceptors in a substrate, the order in which they will be utilized is: (1) oxygen, (2) nitrates, and (3) sulfates. It follows that sulfides will not be produced until the two hydrogen acceptors in the scale above sulfates are satisfied.

From the brief description of the mechanism it is apparent that the following conditions must be fulfilled before sulfate reduction will take place: (1) organic matter must be present, (2) oxygen or nitrates must be absent, (3) sulfates must be present, (4) temperature must be favorable.

It has been known for some time that hydrogen sulfide production from sewage is greatly delayed under laboratory conditions, as compared with the rate of production in sewers. None of the factors mentioned above is altered by the removal of the sewage from the sewer. The explanation points to a specific condition in the sewer which does not exist in the laboratory incubated samples.

It was felt that the difference related somehow to the members of specific sulfate-splitting groups which found conditions more suitable for their growth in the sewer. The only difference in the environmental condition was the presence of sewer growths and sludge deposits, which were excluded in laboratory incubated samples. Baumgartner (1) was able to reduce the lag period considerably by the introduction of stale sewage solids. The evidence was not conclusive, however, since the sewage solids could have been instrumental in stimulating sulfide production by the introduction of additional food. Pomeroy and Bowlus (4), in a thorough and exhaustive contribution to the knowledge of sulfide production in sewers, formulated the principle that in free-flowing sewers, sulfides are produced only by slimes on the submerged surface of the sewer and by deposited sludge. Some time ago we had arrived independently at the same conclusion. The purpose of this paper is to offer an explanation of this phenomenon by presenting some evidence of a bacteriological nature.

Methods

The numbers of sufate-splitting organisms were determined by serial

* Paper of the Journal Series, New Jersey Agricultural Experiment Station, Rutgers University, Department of Sanitation.

dilutions made into the following medium:

K_2HPO_4	0.5 gm.
NH_4Cl	1.0 gm.
Na_2SO_4	1.0 gm.
$MgSO_4$	1.0 gm.
$CaCl_2$	0.1 gm.
Sodium lactate	3.5 gm.
Mohr's salt	trace
Water	1000 ml.

The medium was distributed into test tubes, sterilized, inoculated, and oxygen was excluded by using a rubber stopper on top of alkaline pyrogallol placed on the cotton plugs. After an incubation period of 3 weeks, sulfate-splitting was indicated by the black coloration of iron sulfide.

In studies of sulfide production from sewage and other substrates, the material was distributed into 300-ml. bottles, which were completely filled and stoppered. For each determination one bottle was used and discarded. Sulfides were determined by aspiration of acidified samples with carbon dioxide into zinc acetate solution. Excess iodine was added to the zinc acetate solution at the end of the aspiration period, after which the solution was acidified and titrated with thiosulfate. In work with sterile sewage, all necessary precautions were taken in sterilizing the bottles, and aseptic procedures were employed in handling.

Results

There is relatively little information regarding the numbers of sulfate-splitting organisms in sewage. Hotchkiss (3) reported an average of 3,600 such organisms per ml. of Plainfield, N. J., sewage, and 215,000 per ml. in Imhoff tank sludge. From the standpoint of the lack of sulfate reduction in the flowing body of sewage it is pertinent to inquire whether the organisms are present in the sewage in adequate numbers but do not function because of some unfavorable condition, or whether the limited sulfate reduction is due to an insufficient number of organisms. A third possibility, that the numbers are low because of unfavorable conditions for their development, also presents itself.

Sewages from five different treatment plants were tested for numbers of sulfate-splitting organisms. The results, given in Table I, indicate that the numbers are relatively low. The highest number encountered was in Freehold sewage (600 per ml.), which usually is septic as a result of long detention in the wet well. The samples were all taken in March, which in part might account for the low numbers. During the summer, higher numbers might be expected because of greater activity on the part of these organisms in the sewer.

TABLE I.—Numbers of Sulfate-Splitting Bacteria in Sewage

Source	Numbers (per ml.)
Plainfield, N. J.	250
Manville, N. J.	250
Freehold, N. J.	600
Marlboro, N. J.	130
South River, N. J.	60

The numbers of sulfate-splitting organisms in three types of sludge are given in Table II. The sewer growths were obtained during the spring, when large quantities of this material were being received on the fine screen as a result of discharge from their anchorage in the sewer. The numbers in fresh solids and ripe sludge are higher than those in sewage, but are not as high as might be expected, if sulfate reduction was in active progress in these materials. The quantity of sulfates in the liquid in which fresh solids are suspended is low (as in sewage) and once they are reduced there is no

TABLE II.—Numbers of Sulfate-Splitting Organisms in Sludges

Type Sludge	Numbers (per ml.)
Fresh solids	25,000
Ripe sludge	25,000
Sewer growths	6,000

additional source of sulfates for these organisms.

It was surprising, however, that the sewer growths did not contain higher numbers of sulfate-splitting organisms. It does not seem probable that these growths are the seat of activity in regard to sulfate reduction, since they float on the surface in the direction of the flow, and are anchored at one end. A more likely seat of sulfide production is the bottom deposits. If this is true the number of sulfate-splitting organisms in sewage should increase during scouring flows. It is generally observed that after such flows sulfide production subsides for a time until new bottom accumulations take place.

The effect of chlorine in retarding sulfide production has been reported elsewhere (2). It was, therefore, of interest to show whether the addition of chlorine to sewage results in a reduction of the number of sulfate-reducing organisms. The dosages of chlorine, residual chlorine and numbers of sulfate-splitting organisms after one-half hour of contact are given in Table III. The sewage had a chlorine demand of 15.6 p.p.m., and the addition of 10 p.p.m. of chlorine (60 per cent of the demand) completely eliminated the sulfate-reducing organism in a 1 ml. sample. It has been shown previously (2) that when chlorine is added in an amount equivalent to 25 per cent of the chlorine demand, sulfide production is effectively retarded. In view of this it seems possible that a dosage of less than 60 per cent of the demand

TABLE III.—Effect of Chlorination on Numbers of Sulfate-Splitting Organisms

Chlorine Added (p.p.m.)	Chlorine Residual (p.p.m.)	Number of Organisms (per ml.)
0	0	250
10.0	0	0
15.6	0.1	0
16.0	0.3	0
16.8	1.2	0

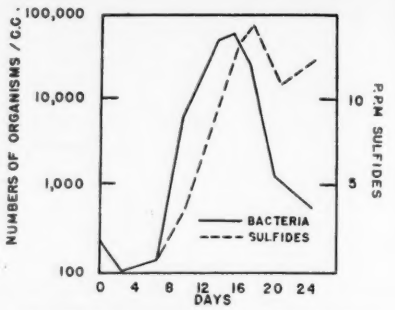

FIGURE 1.—Relation between numbers of sulfate-splitting organisms and the rate of sulfide production.

added in the present study would have reduced the numbers. The original numbers are, however, so few that a quantitative relationship between lower dosages and numbers would be difficult to establish.

One way of showing that an organism in question is responsible for a specific transformation is to correlate the increase in numbers with a product or a change they are supposed to bring about. If the technique of estimating their numbers is sufficiently selective, their numbers should increase simultaneously and in some proportion with their biochemical product. Such a relationship is shown in Figure 1 between the numbers of sulfate-splitting organisms and the rate of hydrogen sulfide production from stored sewage. For 7 days there was no increase in the numbers. Within the next 3 days the numbers increased suddenly to 6,000 per ml., and after an additional 4 days to 50,000 per ml. After an additional increase to 60,000 per ml., the numbers began to decrease sharply on the sixteenth day, and on the twenty-fifth day they were down to a level slightly higher than the initial numbers.

During the initial stationary phase, there was little hydrogen sulfide production. Then with increasing numbers the sulfide content increased to a peak a few days after the peak of

numbers was reached. With decreasing numbers sulfide production was reduced.

The results indicate that the lag in sulfide production is due to: (1) the small number of sulfate-reducing organisms present in the sewage, and (2) the long period of adjustment necessary for their multiplication. Once this adjustment is reached the reaction is rapid. It has the characteristics of an autocatalytic reaction. It indicates that once conditions for multiplication are established, sulfide production can take place within a period compatible with the passage of sewage in the sewer (in terms of hours rather than days). It is pertinent, therefore, to inquire as to the conditions that must be fulfilled before actual multiplication starts.

Before an attempt is made to answer this question, additional evidence, that part of the retardation is due to the limited number of organisms present in sewage, can be presented. In Figure 2 sulfide production from sewage is compared with that from the same sewage to which artificial additions of sulfate-splitting organisms were made from a culture of *Sporovibrio desulfuricans*. It will be seen that sulfide production took place more rapidly, and that a greater amount was produced when the numbers of sulfate-splitting organisms in the sewage were artificially increased. However, it still required 2 days to produce a sulfide content of 1.7 p.p.m.

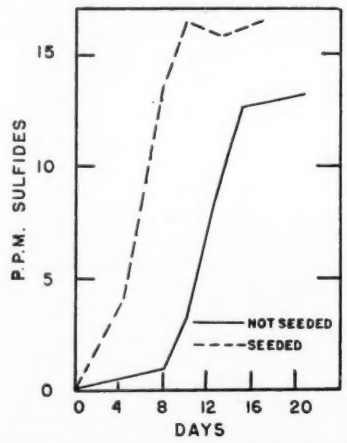

FIGURE 2.—Effect of seeding organisms on sulfide production from sterilized sewage containing sulfide and lactate.

The lag period may be engendered by a limited supply of suitable food, or by the time required for the establishment of the proper oxidation-reduction potential. Baumgartner (1) has shown that the addition of sugar to sewage did not accelerate the rate of sulfide production. It is to be noted that culture media for the cultivation and enumeration of sulfate-splitting organisms contain lactate. It was thought possible that the time required for the active multiplication of these organisms was predicated upon the production in the sewage of substances similar to lactate, by other types of bacteria. Similarly, the preliminary activity of non-reducing organisms might be necessary to create the low oxidation-reduction potential necessary for the growth of sulfate-splitting organisms. For these reasons lactate and sulfide either individually or combined were added to sewage, and the resultant sulfide production studied. One hundred parts per million of sodium lactate and 9 p.p.m. of sodium sulfide were added to samples of sewage and stored. The results are given in Figure 3.

It will be seen that the addition of lactate did not increase the rate of sulfide production. The sulfide added could not be recovered as sulfide immediately after mixture with the sewage. This experiment has been repeated several times with similar results. The nature of the reaction between sewage and sulfide is not known. The lack of knowledge makes the proper evaluation of results difficult, because it is impossible to decide whether increased sulfide production is the result of the added sulfide as such,

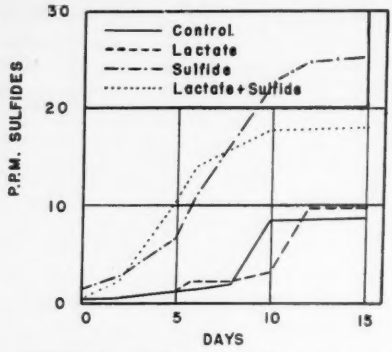

FIGURE 3.—Effect of sulfide and lactate additions on sulfide production from non-sterile sewage.

or is due to the production of sulfides from the compound formed after it has interacted with the sewage.

In order to evaluate the role played by non-sulfate-reducing sewage organisms in sulfide production, sewage was sterilized in an autoclave and inoculated with a culture of *Sporovibrio desulfuricans*. The various treatments consisted of the addition of 100 p.p.m. of sodium lactate and 10 p.p.m. of hydrogen sulfide, either individually or in combination. Aseptic methods were used to exclude contamination by other organisms.

The results are given in Table IV. The striking result in this series is the failure of the added sulfate-splitting culture to produce sulfides in sterilized sewage. This test has been repeated several times with similar results.

That the culture employed is capable of reducing sulfates is demonstrated by the results in Figure 2. The same culture is also able to produce sulfides in culture medium, as will be shown below. In the absence of other organisms in sterile sewage, the culture is unable to produce sulfides.

Upon addition of hydrogen sulfide either alone or in combination with lactate, however, sulfide production was active. In this respect the results are similar to those obtained with non-sterile sewage as presented in Figure 3. But again the results are subject to reservations, because of the failure of initial full recovery of the added sulfide. It might be safe to conclude, however, that the added sulfide is able to overcome the inability of cultures of sulfate-splitting organisms to reduce sulfate in sterile sewage. It appears that the non-sulfate-splitting organisms play a role in reducing the oxidation-reduction potential of the sewage, and if these organisms are eliminated sulfate reduction cannot take place by the cultures alone unless the oxidation-reduction potential is reduced artificially by the addition of some reducing agent.

A comparison of sulfide production with two different concentrations of lactate in culture medium, or added to sterile sewage, is given in Table V. The culture medium was made according to the formula given above, keeping in one case the lactate concentration at the usual value of 3,500 p.p.m., and in the other reducing it to 100 p.p.m. These two concentrations of lactate were added also to sterile sewage. All media were inoculated with

TABLE IV.—Effect on Sulfide Production of the Addition of Sulfide and Lactate to Sterile Sewage Inoculated with Sulfate-Splitting Organisms

No.	Culture	H_2S	Lactate	Sulfide Produced After Indicated Days Incubation (p.p.m.)							
				0	1	2	3	4	6	7	9
1	+	0	0	0	0.5	0.3	0.3	0.3	0.6	0.6	0.6
2	+	+	0	2.1	7.7	8.6	9.1	9.3	10.8	10.5	10.4
3	+	0	+	0	0.3	0.2	0.3	0.3	0.6	0.4	0.6
4	+	+	+	5.3	5.1	7.3	11.5	17.7	20.7	19.7	19.7

TABLE V.—Sulfide Production from Nutrient Solution and Heat-Sterilized Sewage Inoculated with Sulfate-Splitting Organisms

No.	Substrate	Lactate (p.p.m.)	Sulfide Produced After Indicated Days Incubation (p.p.m.)							
			0	2	4	6	8	10	12	28
1	Culture media	3500	0.6	0.6	0	38.5	148.7	—	223	330
2	Culture media	100	0.6	0.7	0.4	0.6	0.5	0.8	0.1	0
3	Sterile sewage	3500	0.6	1.0	0	0.4	0.5	0	0	0
4	Sterile sewage	100	0.6	0.6	0	0.4	0.4	0	0	0

the same culture of *Sporovibrio desulfuricans*.

It will be seen that only the culture medium with 3,500 p.p.m. of lactate produced sulfide in large quantities. Even in this case there was a lag period of 4 days, after which sulfides accumulated rapidly until a concentration of 220 p.p.m. was attained in 12 days. With 100 p.p.m. of lactate, however, sulfide production was meager (less than 1.0 p.p.m.), although this medium contained the same high sulfate content as the medium to which 3,500 p.p.m. lactate were added. In sterile sewage the addition of 3,500 p.p.m. of lactate was of little avail in promoting sulfide production.

That the failure of sulfide production from sterile sewage is not due to some chemical changes, but to a biological factor, is shown in the following experiment, where sterilized sewage was reseeded with 1 per cent of non-sterile sewage (Table VI). In the absence of lactate, only small irregular amounts of sulfides were produced. With 100 p.p.m. of lactate, 12 p.p.m. of sulfide was produced in 12 days. It should be remembered that with 1 per cent of sewage the initial numbers of sulfate-splitting organisms were limited, in view of the small numbers present in the seed sewage.

TABLE VI.—Sulfide Production from Sterile Sewage Inoculated with Sewage Containing Various Concentrations of Lactate

Lactate (p.p.m.)	Sulfide Production After Indicated Days Incubation (p.p.m.)							
	0	2	4	6	8	10	12	28
0	0.6	0.4	0	0.4	1.2	0.7	0.3	0
100	0.6	1.3	0.6	0.8	1.0	0.3	0.5	6.0
3500	0.6	2.2	0.6	0.4	0.5	12.2	12.2	—

Discussion

The ability to reduce sulfates is not widespread among bacteria. It is restricted to a few closely related organisms. These organisms are commonly found in sewage, bottom deposits, in lakes, streams and canals, in soil and sea water, and in other environments. Their numbers in sewage, however, are restricted. In solid deposits, such as fresh solids, ripe sludge, and sewer growths, the numbers of these organisms are higher, but even in these materials their numbers are not excessively high. When sewage is stored in the laboratory the numbers of these organisms do not increase immediately, but remain at the initial low level for about a week. During this period the sulfide content of the sewage remains low; thereafter the numbers increase to a maximum and simultaneously sulfides increase. Even at the peak of activity the numbers are not extremely high (60,000 per ml.).

What is the cause of the prolonged lag period? Is it dependent upon some biochemical change in the sewage itself? These questions are important in the explanation of the lack of sulfide generation in free-flowing sewage. That the low numbers present in the sewage are partly responsible for the

delayed action is shown by the decrease in the lag period and the increased rate of sulfide production upon artificial addition of sulfate-reducing organisms. Yet, this is not an adequate explanation, because even with artificial addition of culture the sulfide content of the stored sewage does not reach a level comparable to that reached within a usual period of 6 to 10 hours of detention in sewers. In long sewers, especially when summer temperatures prevail, dissolved oxygen (which would retard the reduction of sulfates) does not exist. Although surface aeration introduces some oxygen to the sewage it normally is not sufficient to give a detectable amount of dissolved oxygen on account of its rapid rate of utilization. It is doubtful under these conditions of surface aeration, and in the absence of a positive dissolved oxygen level, that the sulfate-reducing organisms would actually be inhibited.

Nitrates are not present in normal domestic sewage in detectable quantities. Organic matter in various stages of decomposition is a normal ingredient of sewage. Sulfates are also present in varying quantities, depending upon the character of the water supply. The explanation must, therefore, rest on the biochemical condition of the sewage. The experiments recorded show that in sewage the exclusion of non-sulfate-splitting organisms results in an inhibition of sulfate reduction. It follows, therefore, that the non-sulfate-splitting organisms may play a role in fostering the activities of the sulfate-reducing organisms.

The role could be associated with either the preparation of the organic material into a form available for the sulfate-reducing organism, or the lowering of the oxidation-reduction potential to a level favorable for the growth of sulfate-reducing organisms. The first alternative does not seem probable in view of the failure of the addition of sodium lactate to the sewage in increasing sulfide production.

The increase in sulfate reduction upon the addition of sulfides to sewage points to the probability that the lag period is dependent upon the creation of a proper oxidation-reduction level in the sewage by non-sulfate-splitting organisms. It is to be expected that the oxidation-reduction potential would be lowered by the production of sulfides. By the same token the artificial addition of sulfide should lower the potential. If the initial lag in sulfide production is determined by the high potential, then artificial addition of sulfide should stimulate the growth of sulfate-splitting organisms and increase sulfide production.

The abundance of sulfate-reducing organisms and their high rate of activity in the bottom sludge deposits could also be attributed to the low oxidation-reduction potential in such deposits. In such an environment the organisms could multiply and produce hydrogen sulfide at a rapid rate, provided sulfates were furnished to them. The sulfates are supplied to the organisms by the sewage continuously flowing over them, so that their activity is kept at the maximum rate and is influenced only by the temperature. The type of action might be visualized as an anaerobic trickling filter with an established flora and a continuous supply of food passing over it. The sulfates are reduced and diffused back to the sewage.

There are some facts that are incompatible with the above conclusion. If the failure of sulfide production in sewage in the absence of non-sulfide-producing organisms is due to the role played by the latter in reducing the oxidation-reduction potential, then why in culture medium are sulfate-reducing bacteria able to reduce sulfates in the absence of such non-sulfide-producing organisms? The addition of

sodium lactate to the sterilized sewage in a concentration equal to that in a culture medium did not increase sulfide production.

The sulfate-reducing organisms are active over a wide range of pH values. Pomeroy and Bowlus (4) give a range of pH values from 6 to 9. The pH values of the sewage increased from 7 to 8 upon sterilization. It does not seem probable, therefore, that the failure of the cultures to produce sulfide in sterilized sewage is caused by too low or too high a pH value.

Summary and Conclusions

The numbers of sulfate-reducing organisms in sewage and sludges were determined. The effect of chlorination on the number of sulfate-reducing organisms was shown. The increase in numbers of these organisms with hydrogen sulfide production in stored sewage was compared. The numbers of sulfate-reducing organisms were increased by artificial addition of cultures, and their effect on sulfide production from stored sewage was determined. The effect of the addition of sodium lactate and of sulfide to sterile and non-sterile sewage was studied. The results indicate that:

(1) The numbers of sulfate-reducing organisms in sewage are low. Greater numbers of these organisms are found in various sludges.

(2) Subresidual chlorine dosage (60 per cent of the demand) is effective in destroying these organisms.

(3) The numbers of sulfate-reducing organisms and the rate of sulfide production in stored sewage show a good correlation. The numbers of organisms and sulfide production both show a definite initial lag. The lag period is considerably shortened by the addition of a culture of *Sporovibrio desulfuricans.*

(4) The addition of sodium lactate to sewage does not increase the rate of sulfide production.

(5) The addition of sulfide to sewage increases the rate of sulfide production.

(6) Heat-sterilized sewage failed to produce sulfide upon inoculation with cultures of *Sporovibrio desulfuricans.* The failure of sulfide production under these conditions was counteracted by the addition of sulfide, but not by the addition of lactate.

(7) The lag in sulfide production in stored sewage and the failure of sulfide production in the flowing body of sewage in sewers are caused by the unfavorable oxidation-reduction potential. The oxidation-reduction potential is lowered by the activity of non-sulfate-splitting organisms and, after sulfide production has been initiated, by the sulfides themselves.

The results lead to the following generalizations: In sewers the detention time of the flowing portion of the sewage is not long enough to bring about a sufficiently low oxidation-reduction potential, with the result that the organisms do not multiply and hydrogen sulfide is not produced. In the sludge deposits the oxidation-reduction potential is low, a large number of organisms are found, and the resultant rate of activity is high under favorable temperature conditions. The function of the flowing portion of the sewage is to furnish a continuous supply of sulfates, which after reduction in the sludge are diffused back to the sewage.

In stored sewage the lag period is predicated on the activity of non-sulfate-reducing organisms in lowering the oxidation-reduction potential to a level favorable to sulfate-reducing organisms. Thereafter, the production of sulfide further lowers the potential and gives rise to an autocatalytic reac-

tion. In the absence of non-sulfate-reducing organisms the only way sulfide production can be initiated is by the addition of some reducing agent such as sulfide.

Acknowledgment

The culture of *Sporovibrio desulfuricans* was kindly furnished by Dr. R. L. Starkey of the Department of Microbiology, Rutgers University.

References

1. Baumgartner, Wm. H., "Effect of Temperature and Seeding on Hydrogen Sulfide Formation in Sewage." THIS JOURNAL, **6**, 399 (1934).
2. Heukelekian, H., "Sewage Chlorination for Odor Control." *Water Works and Sewerage*, **69**, 302 (1942).
3. Hotchkiss, Margaret, "Studies on the Biology of Sewage Disposal. A Survey of the Bacteriological Flora of a Sewage Treatment Plant." *Journal of Bacteriology*, **9**, 437 (1924).
4. Pomeroy, R., and Bowlus, F. D., "Progress Report on Sulfide Control Research." THIS JOURNAL, **18**, 597 (1946).

USPHS PERSONNEL CHANGES

The retirement on January 1, 1948, of J. K. Hoskins as Assistant Surgeon General of the U. S. Public Health Service was the first of several important personnel changes to take place in that federal agency recently. Mr. Hoskins leaves a fine record of 34 years duration in the Service, and was the first Chief of the Sanitary Engineering Division to assume the title of Assistant Surgeon General, when the Service was reorganized early in World War II. He served as President of the Federation of Sewage Works Associations during the year 1945–46, the year the foundation was laid for the present rapid growth of the international organization.

Mr. Hoskins has been succeeded as Assistant Surgeon General by Mark D. Hollis, who has been on the staff of the Sanitary Engineering Division since 1934 except for a short period in which he served as state sanitary engineer of North Dakota. He was commissioned into the Regular Corps in 1941. Mr. Hollis is now in charge of all USPHS sanitary engineering functions.

The second notable change took place on April 6, when Dr. Thomas Parran completed his third 4-year term as Surgeon General, and was succeeded in the position by Dr. Leonard A. Scheele. The Service and its broad activity program were strengthened in many ways under Dr. Parran's leadership, including expansion of the Sanitary Engineering Division. He has also demonstrated great interest in stream pollution control and has been a strong proponent of federal anti-pollution legislation. Dr. Scheele has been a member of the Regular Corps of the Service since 1934, and held the rank of Assistant Surgeon General prior to his present appointment.

Another significant loss to the Sanitary Engineering Division took place in April upon the retirement of Harold W. Streeter, Sanitary Engineer Director of the USPHS Water and Sanitation Investigations Station at Cincinnati. Mr. Streeter has made many important technical contributions in his 34 years of duty in the Service; he is presently an outstanding authority on studies of natural purification in streams. Mr. Streeter has been active in the Federation since its beginning, having served on the Organization Committee in 1928 and as Director-at-Large from 1928 to 1941. He has also served on the Awards Committee (1946) and on the Membership Committee (1929 to 1939). In 1945 he received the Charles Alvin Emerson Award for outstanding service to the Federation. He is also a member of the Quarter-Century Operators Club.

The death on January 23, 1948, of Ralph E. Tarbett closed the career of another prominent figure in the USPHS. Mr. Tarbett retired in 1947 after 34 years in the Service, during which time he handled a large number of important assignments.

DETERMINATION OF HYDROGEN SULFIDE IN DIGESTER GAS

By Frederick E. Nussberger

Chemist, Department of Public Works, New York City

There have been many methods proposed for the determination of hydrogen sulfide in various industrial gases. The procedure described herein is an adaptation of several of these methods, and is specifically modified for the determination of hydrogen sulfide in digester gas.

Digester gas is usually collected under a pressure of 4 to 8 in. of water. As this pressure is too low to allow a free bubbling through a sufficient depth of absorbing solution, an aspirator is provided to draw the gas through about 10-in. of solution. The volume of gas drawn through the solution is measured by calibrations on the aspirator bottle. The absorbing solution used is a 1 per cent solution of cadmium acetate in 1 per cent acetic acid. It is necessary to use an acid absorbing solution because of the high carbon dioxide content of digester gas. The quantity of hydrogen sulfide absorbed is determined by a titration with standard iodine solution.

Present Methods

It may be of interest to review briefly some of the published methods for the determination of hydrogen sulfide in various industrial gases. The Tutweiler method (1) provides for an absorption of the hydrogen sulfide in standard iodine solution. The lead acetate test (2) depends upon the darkening of a strip of paper impregnated with lead acetate and exposed to a measured volume of gas. Various combustion methods (3) for determining total sulfur in gas provide for an absorption of the products of combustion of the gas in a solution of amoxidation of the sulfur oxides, and a determination of the sulfate either monia or ammonium carbonate, an gravimetrically, volumetrically, or turbidimetrically.

An absorption method (4) employs either a solution of sodium hydroxide, ammoniacal cadmium chloride, or ammoniacal zinc sulfate for the absorption of hydrogen sulfide, with subsequent acidification and titration with standard iodine or iodate solution. Another absorption method (5) employs an absorber having a fritted glass plate and a spray trap, and absorbs the hydrogen sulfide in a cadmium sulfate solution to which standard iodine solution is added in excess, with a back titration by standard thiosulfate. Another absorption method (6) employs a 5 per cent solution of cadmium acetate in 5 per cent acetic acid for absorption of hydrogen sulfide, and a wet test meter for measuring the volume of gas.

Proposed Method

The method that follows is offered as a routine method for the determination of hydrogen sulfide in digester gas. When the precautions are taken as noted, the method is accurate and rapid.

The apparatus and method of operation is best described with reference to Figure 1, where **1** and **2** are absorption cylinders of about 250 ml. capacity each; **3** and **4** are bottles of about 5 gal. capacity each, **3** being calibrated at 2-liter intervals; **5** and **6** are screw clamps; **7** is a mercury manometer;

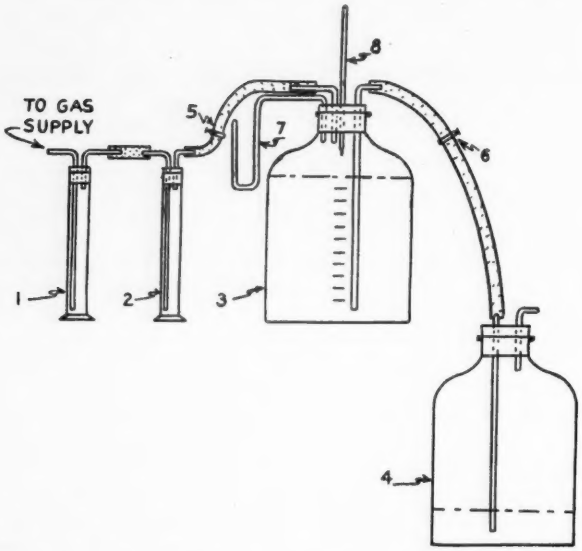

FIGURE 1.—Apparatus for determination of hydrogen sulfide content of digester gas.

and **8** is a thermometer. The siphon tubing should have an inside diameter of 6 mm. or greater.

About 150 ml. of a solution of 1 per cent cadmium acetate in 1 per cent acetic acid are placed in each of the cylinders. To the water in the 5-gal. bottle is added 50 ml. of concentrated sulfuric acid (to reduce the solubility of carbon dioxide in the water). The solution should be at room temperature before making the determination.

In order to saturate this water with the gas, and in order to saturate the rubber tubing connection from the gas-cock to the cylinder, several trial runs should be made before the actual determination. The connection from the gas-cock to the cylinder should be mainly of glass tubing, using only short pieces of rubber tubing to make the connections. The inside of the glass tubing and rubber connections from the gas-cock to the cylinder must be kept dry, since any water inside this connection will vitiate the determination.

A suitable purge, such as a gas burner, must be provided and operated during the determination if the gas connection is not taken off a main. Check for air-tight connections by closing the gas-cock, opening the screw clamps until maximum vacuum is indicated on the manometer, and then closing screw clamp **6** and observing if the level of the mercury changes over a period of a few minutes.

Begin the determination by opening the gas-cock, then opening screw clamp **5** and then gradually opening screw clamp **6** until gas is bubbling through cylinders **1** and **2** at a moderate rate (about 2 liters of gas per 10 minutes). The volume of gas to be taken for each determination will depend on the hydrogen sulfide content of the gas. If the gas has a hydrogen sulfide content of about 50 grains per 100 cu. ft., take 2 liters of the gas. If the hydrogen sulfide content is about 5 grains per 100 cu. ft., take 6 or 8 liters of the gas per determination. Make at least two and preferably three determinations,

and take the average value of the amounts of hydrogen sulfide found. Take readings on the manometer and on the thermometer.

When the requisite amount of gas has been run through the absorbing solution, close the screw clamp **6**, then close the screw clamp **5**, and then close the gas-cock. Transfer the solution plus the cadmium sulfide precipitate quantitatively to a 1-liter florence flask, using water acidified with hydrochloric acid to remove adhering precipitate. Then add sufficient water to make the volume in the flask about 400 ml., and add sufficient hydrochloric acid, 1 to 1, to dissolve the precipitate (about 25 ml.).

To minimize loss of hydrogen sulfide from the solution, do not agitate the solution unduly. Add 5 ml. of 1 per cent starch solution and titrate with 0.01 N iodine solution to the appearance of a blue color. All the hydrogen sulfide should be absorbed in cylinder **1**, and it will not ordinarily be necessary to titrate the solution in cylinder **2**. Run a blank using the same volumes of cadmium acetate solution, hydrochloric acid, water, and starch to determine the volume of iodine solution required to produce a perceptible blue color in the solution.

Calculation

1.0 ml. of 0.01 N iodine solution is equivalent to 0.00263 grains of hydrogen sulfide, therefore:

$$\frac{\text{ml. 0.01 N iodine} \times 7.44}{\text{liters gas}} = \text{grains } H_2S \text{ per 100 cu. ft.}$$

If it is desired to correct the above value to grains H_2S per 100 cu. ft. of saturated gas at 60° F. and 30 in. Hg, substitute for the liters of gas as measured a corrected volume obtained from the equation:

$$V_c = V_o\left[\frac{P_a-(P_v+P_w)}{30.00-0.52}\right]\left[\frac{520}{460+T}\right]$$

where V_c = corrected volume of gas used for the determination
V_o = volume of gas as measured
P_a = atmospheric pressure in inches Hg
P_v = manometer reading in inches Hg
P_w = vapor pressure of water at the temperature of the gas in the bottle, in inches Hg
T = temperature of the gas in the bottle in degrees F.

References

1. Report of Investigation No. 3128, "Hydrogen Sulfide Content of the Gas in Some Producing Oil Fields." U. S. Department of the Interior, Bureau of Mines (1931).
2. Technologic Paper No. 41, "Lead Acetate Test for Hydrogen Sulfide in Gas." U. S. Bureau of Standards (1914).
3. Technologic Paper No. 20, "Determination of Sulfur in Illuminating Gas." U. S. Bureau of Standards (1913).
4. "Methods of the Chemists of the U. S. Steel Corporation for the Sampling and Analysis of Gases" (1927).
5. "Code for Measuring, Sampling and Testing Natural Gas." American Petroleum Institute, New York City (1942).
6. Private Communication: Mr. E. J. Murphy, Chief Chemist, Brooklyn Union Gas Company, Brooklyn, N. Y.

ENGINEERING PLANNING OF SEWAGE COLLECTION AND TREATMENT *

By Earnest Boyce

Professor of Municipal and Sanitary Engineering, University of Michigan, Ann Arbor, Mich.

The sanitary utility services of public water supply and sewage collection and treatment, like many other engineering achievements, are relatively new in the history of man's attempts to control and modify his environment for his greater comfort and convenience.

We are prone to measure the changes that take place in our surroundings with the very short yardstick of what we have seen happen in our time, and because of the very shortness of this yardstick, we may fail to appreciate the full significance of these changes. Modern sewage works practice is less than 100 years old. It was not until 1847 that a metropolitan commission was created to study the sewage problem in London. In 1857 a system of combined sewers was designed to serve the city of Brooklyn and the following year sewers were planned for Chicago.

Early Practice

It is of interest to note that the earlier sewers were designed for street drainage only. For example, the public drains in Boston were closed to sanitary wastes until 1833, and the famed sewers of Paris were not used for sanitary purposes until 1880, a date of special interest, for it was in that year that the first sewer was designed for the separate removal of the domestic sewage of the city of Memphis.

The early designers, responding to a public appreciation of the importance of removing sewage wastes as a public health measure, pioneered in the development of systems of sewers on the basis of such design data as then appeared to be reasonable. They planned well for the situations with which they were then confronted, so well in fact that there may be a reluctance to recognize the present obsolescence of some of these earlier designs.

It was logical that existing storm sewers should have been extended and modified to remove sanitary drainage, and that this combined sewer plan should have been followed in the 200 cities of this country that had systems of sewers prior to the design of the original separate sanitary sewer in 1880. So long as these and the many subsequently designed systems of combined sewers continue to provide reasonably satisfactory means for the removal of the mixed flow of storm, domestic, and industrial waters, it is equally logical to believe that there will be some reluctance to face the stream pollution problems that result from the shortcomings of methods of disposal of these mixed flows.

Health Protection at a Price

The removal of sewage wastes by the water carriage method has served a great public health need and has made possible the present high standards of health protection. As a utility service, however, the practice has failed to solve many of the long-range problems that are created by this method of waste removal. Public health protection has been secured, but at a price. If the price, which is the cost of the

* Presented at 22nd Annual Conference of the Michigan Sewage Works Association, Jackson, Mich., May 15, 1947.

stream pollution that results from this method of sewage and waste disposal, is within our ability to pay, then it may be assumed that as yet we are not bankrupt in our water resources. It is well to remember, however, that as populations and industry increase, sewage flows will likewise increase, and in the future it may not be possible to keep sources of water supply free from objectionable concentrations of pollution, unless methods of sewage collection and treatment keep pace with this increasing load.

Public health protection from waterborne disease has been made secure through improvements in the art of water purification, despite a steady deterioration in the quality of many surface water sources. Procedures in water treatment that were once regarded as factors of safety are now considered essential to the production of safe water. Typhoid fever control became effective only when water disinfection was developed as a necessary part of the treatment process.

Because of the public health security that has been achieved through improved methods of water purification, there is an unwarranted complacency with regard to the increase in waterways pollution. Problems of water quality are not made the subject of careful analysis when major river basins are studied for irrigation or flood control, and too frequently water pollution becomes a matter of public concern only when oxygen depletion creates offense.

Sewage Treatment Policy

There exists a popular but naive belief that all stream pollution problems can be solved by building sewage treatment plants. Because the putrefactive capacity of organic wastes of domestic origin can be controlled, a tacit assumption exists that all wastes can be treated with equal facility. This public confidence in sewage treatment should not be shaken by any failure to indicate clearly the limitations of present disposal methods. The public should know that essential industries must produce wastes that are both chemically and biologically inert, and that no known method of sewage treatment will greatly change the objectionable characteristics of some of these wastes.

On the part of industrial management there needs to be a willingness to recognize that the problems of waste disposal are basic, and that in some instances they may well become a determining factor in plant site selection. Unfortunately, many stream pollution control laws fail to permit action in anticipation of future pollution problems, and in consequence industries may be located and built so that destructive stream pollution becomes inevitable.

While progress in stream sanitation is being made, there is reason to doubt that the rate of progress is as great as the rate of increase of the pollution load. The U. S. Public Health Service has estimated that a total of 71 million persons are served by public sewers, but that the total pollutional load on our waterways due to both domestic and industrial wastes exceeds the equivalent waste of 100 million persons. These figures, compiled as of 1942 and in which there has been but little subsequent change, show that the sewage wastes of approximately 42 million persons out of the 71 million total are given some degree of treatment. This treatment, however, is equivalent to complete treatment of the sewage of only about 24 million persons. The same source has estimated that the pollutional load of industry is approximately equal to the untreated domestic sewage load.

It would be misleading to assume that partial sewage treatment may not be adequate in many situations, or that sewage treatment of some form will be required in all instances, but it is increasingly evident that many

cities which have not previously considered the necessity of sewage treatment are now facing that eventuality.

Storm Flow Diversion

Many cities have systems of combined sewers, designed and constructed to remove storm drainage and sanitary sewage for disposal by dilution. So long as lakes and rivers could be used for this method of disposal, the mixing of storm and sanitary drainage created no serious problem. But problems do develop when the treatment of sanitary drainage becomes a necessity.

Intercepting sewers and sewage treatment facilities are designed to handle flows somewhat in excess of the maximum dry weather flow in the combined sewer. As much as three to five times the average dry weather flow may be diverted for treatment. Few sewage treatment plants can be expected to function effectively when peak flows exceed such variations from normal, yet the bypassed flow in excess of these dilutions may easily produce objectionable pollution in the receiving body of water. From the standpoint of pollution control it is necessary to arrive at some rational basis for determining the degree of sanitary sewage dilution required before treatment plant bypassing may be permissible.

When the bypassed flow enters the same body of water that receives the treatment plant effluent, it would appear logical that this flow should not increase the pollution of the receiving body of water beyond that occasioned by the plant effluent.

If only primary treatment is required, then the suspended organic solids in the bypassed flow should not exceed those normally present in the effluent of the treatment plant. If complete oxidizing treatment is necessary, then the B.O.D. of the bypassed flow should be reduced by dilution to that maintained in the plant effluent. If recreational use or shellfish culture requires the maintenance of a bacterial standard in the treated sewage, that standard will be jeopardized unless the bypassed portion of the flow from a combined sewer is equally free from objectionable bacterial pollution.

Although this basis of determining a permissible dilution of sanitary sewage before bypassing of storm water flow might appear logical, it would produce peak flows far in excess of the practical limits of treatment plant design. An example will illustrate this point. Assume that the dry weather flow from a combined sewer has an average B.O.D. of 300 p.p.m. and that by treatment in an activated sludge plant this is reduced to 15 p.p.m. To reduce the storm flow to 15 p.p.m. B.O.D. would require the treatment of all flows less than twenty times the average dry weather flow.

Assuming that storm runoff doubles the flow in a receiving river by the time the bypass operated, the treatment of ten times the dry weather flow would still be indicated if the concentration of the pollutional load is not to be increased.

Because sewage treatment plants cannot effectively handle the variations in load produced by these peak flows, regardless of the excessive construction and operation costs were such plants to be provided, it follows that most sewage treatment plants treating sewage from systems of combined sewers must, of necessity, fail at times of storm flow to provide the degree of pollution control maintained during periods of dry weather flow. It likewise follows that the stream or waterway usages must be limited to those that can be carried forward despite the occasional pollutional loadings of the bypassed combined sewage. If reasonable standards of water quality are to be maintained in many rivers and lakes, the time may come—if indeed it is not here—when some cities may find it economical to separate the

used water of a community that requires treatment from the storm water runoff by the construction of separate sanitary sewers.

Industrial Waste Policy

A second problem incident to the collection and removal of the sewage of a city is in connection with the handling of certain industrial wastes. Engineering practice has developed well-defined procedures for the treatment of domestic sewage. It is frequently assumed that the various kinds of industrial wastes can be treated in the same type of plant used for domestic sewage, providing the design capacities are properly adjusted.

Many industrial wastes are of unstable organic character and are, consequently, similarly susceptible to biological treatment. There are other wastes, however, that not only do not respond to the treatment processes normally used for domestic sewage, but which also may exert an inhibiting effect on the treatment of the domestic sewage with which they may be mixed.

In some instances, by prior treatment at the industrial plant or by a controlled rate of discharge, it may be possible to treat mixed industrial and domestic sewage flows in a central plant. There is danger, however, in assuming that all wastes can be so treated.

Each industry seeking an outlet for its liquid wastes through public sewers should be expected to contribute to such sewage flow only those wastes that can be treated by the processes normally used for sanitary sewage. The special processing that may be necessary for special types of industrial wastes may require the construction of special industrial sewers both within and without the industrial plant.

The successful control of river pollution will require the further development of the notable interest that is now being shown in pollution abatement by those industries whose managements recognize their responsibility in this phase of operational procedure.

Uniformity of Effluent Quality

We are properly reminded from time to time that it is not the average situation that causes trouble, a statement that is very true when we consider problems of sewage treatment and stream pollution control. Fish are not kept alive by the average dissolved oxygen content of a river. It is not the average but the deviations from the average that destroy fish life and provide the maximum loadings that limit the usefulness of streams used in the disposal of domestic and industrial wastes.

Interest therefore centers on sewage treatment plant designs and processes that possess the capacity to produce uniformly satisfactory effluents despite wide fluctuations in the volume and organic load of the incoming sewage. The results of analysis of an effluent sample composited over a 24-hr. period may be completely satisfactory, yet discharges may be occurring during periods of peak flow that fall far below the minimum standard of quality demanded of the plant. There is a need to analyze carefully the capacity of sewage treatment plants to produce, not percentage reductions of the loads imposed hour by hour, but rather to operate so that at no time will the stream flowing past the treatment plant receive an effluent causing instantaneous loadings in excess of prescribed standards.

In this connection the equalizing effect of effluent lagoons may well be considered. If the analysis of a 24-hr. composite effluent sample meets the quality standard to be maintained in the receiving stream, an equalizing lagoon or storage reservoir holding a quantity somewhat in excess of the 24-hr. flow can be used to insure that effluent of uniform quality is discharged.

By increasing the length of storage time in terminal lagoons protection against the variations in quality that may occur in a cycle of several days operation can be provided.

Summary

The engineering planning of sewage collection and treatment facilities should not be regarded as having reached such a level of perfection that further changes should not be considered. Progress is made when we recognize the defects existing in current practice, and concern ourselves with methods for remedying these defects.

Sewage collection and treatment facilities are relatively long lived and, unfortunately, old designs may be modified but seldom discarded. Consequently, what we design and build now should be planned with an appreciation of the problems that may become more critical in the future, and of the possible modifications that may then be required.

Finally, there is a need to keep the public well informed with regard to the following problems of stream sanitation: (1) that the methods of sewage collection now in use limit the degree of treatment that can be effected; (2) that certain industrial wastes cannot be satisfactorily disposed of through the type of sewage treatment plant required for the treatment of domestic sewage, and that further research is needed to develop workable disposal methods for some of these industrial wastes; (3) that average values, when used to measure the quality of the effluent produced by a plant, may fail to reveal critical conditions which may occur during the periods of peak volume and sewage concentration loadings of the plant. The effectiveness of the treatment process depends on its ability to produce at all hours of the day and at all seasons of the year an effluent that does not destroy the further usefulness of the receiving waters.

ENGINEERING PLANNING OF SEWAGE COLLECTION AND TREATMENT WORKS—A DISCUSSION

By W. R. Drury

Partner, Shoecraft, Drury and McNamee, Consulting Engineers, Ann Arbor, Mich.

The paper given by Mr. Boyce is quite fundamental in its aspects and gives considerable food for thought and further analysis.

In the last paragraph of the paper, three definite problems of stream sanitation control are summarized. The writer will discuss these three problems and will refer to a fourth consideration which the paper does not suggest.

Sewage Collection Methods

The first problem to be considered is that sewage collection methods limit the degree of sewage treatment. This is a statement that leads to the consideration of the use of separate and combined sewers.

The separate system, in which a system of sanitary sewers is provided to carry only sanitary sewage and industrial waste but no storm water, is theoretically a good system to follow. From a practical standpoint, however, there are many difficulties in the design, construction, and use of a separate sanitary sewer system.

The fact that sewers and sewer connections to buildings are structures that are buried beneath the ground and never seen again after they are built makes it necessary that the most careful inspection and supervision be given during their construction. It is practically impossible, however, to control construction to such an extent that every house connection will be properly

made to the proper sewer. Often street inlets are connected to sanitary sewers by mistake and roof water leaders many times are connected with the plumbing of buildings, to the end that a large amount of storm water reaches the sanitary sewer.

Experience in many cities which have separate sewers indicates the difficulty of policing such a system to exclude storm water. In some cases this has led to the design of a modified separate sewer system which is planned to carry sanitary sewage and a certain amount of roof water from residences. Street drainage, however, is kept out of the sanitary sewer and is discharged into a separate storm sewer. Such a system was installed for the city of Midland, Mich., some years ago and, so far as is known, is in successful use.

However good a separate sanitary sewer system might be considered to be, it is economically impracticable and impossible to change from a combined system of sewers to a separate system in a large and developed city. The cost of building completely new sanitary sewers would be prohibitive, and the public generally would not be in sympathy with the tearing up of streets for such a purpose. In addition, the matter of changing every house connection to make sure that only sanitary sewage was admitted to the sanitary sewer would be a problem beyond any practical consideration.

Combined sewers, on the other hand, are much simpler to design since only one system of sewers need to be provided. The problem of segregation of storm water from sanitary sewage is completely obviated, and the control of house and building connections and of inlet connections is simplified.

In the matter of sewage treatment, something can be said for combined sewers in that the first wash of the dirt and filth from the streets can be carried to the sewage treatment plant and given treatment. In the separate storm sewer system, however, this advantage does not obtain, and no treatment is given to the first wash from the streets.

It is a question, therefore, as to which is better, a separate or a combined system of sewers. Much can be said for both systems. The fact that most large cities have combined sewers makes it necessary to consider the effect of this type of sewer system on the design of the sewage treatment plant.

Dilution Considerations

Mr. Boyce has referred in his paper to certain dilution ratios that might be considered in the treatment of combined sewage. In this connection, the writer has developed several typical problems of design which might be considered. These examples are based on certain assumptions and are not conclusive in their results, but are given for the purpose of stimulating interest and to show how such problems might be analyzed. The four typical cases considered include, first, a primary treatment plant handling dry weather flow (Figure 1); second, a primary treatment plant handling wet weather flow (Figure 2); third, a complete treatment plant handling dry weather flow (Figure 3); and fourth, a complete treatment plant handling wet weather flow (Figure 4).

Figure 1 shows a receiving stream with 100 c.f.s. dry weather flow and a sewer, primary sewage treatment plant, and outfall handling 10 c.f.s. dry weather flow, with suspended solids of 300 p.p.m. or 16,200 lb. per day. With the plant removing 60 per cent of the suspended solids and leaving 40 per cent to go into the stream, the effluent of 10 c.f.s. carries 120 p.p.m. of suspended solids, or 6,480 lb. per day. The receiving stream with a total flow of 110 c.f.s. then has finally a suspended solids content of 11 p.p.m.

Figure 2 shows a receiving stream with 150 c.f.s. of wet weather flow and a sewer carrying 30 c.f.s. of combined

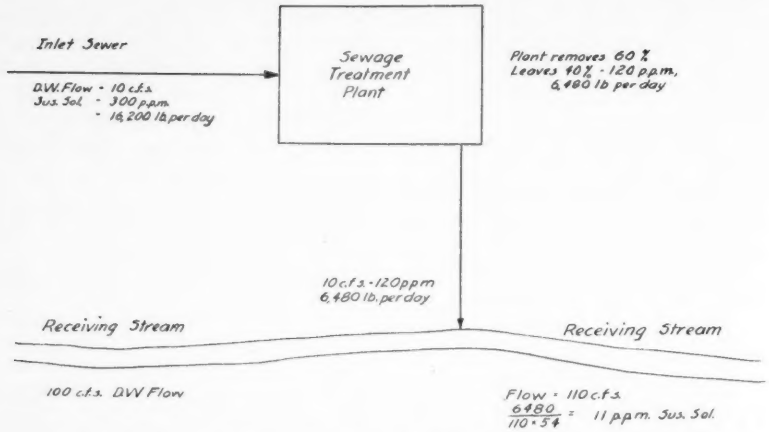
Inlet Sewer
D.W. Flow - 10 c.f.s.
Sus. Sol - 300 p.p.m.
- 16,200 lb. per day
Sewage Treatment Plant
Plant removes 60 %
Leaves 40 % - 120 p.p.m.
6,480 lb per day
10 c.f.s. - 120 p.p.m
6,480 lb. per day
Receiving Stream
Receiving Stream
100 c.f.s. D.W. Flow
Flow = 110 c.f.s.
6480 / 110 * 5.4 = 11 p.p.m. Sus. Sol.

FIGURE 1.—Illustration of suspended solids loading of stream receiving effluent from a primary treatment plant under dry weather flow conditions.

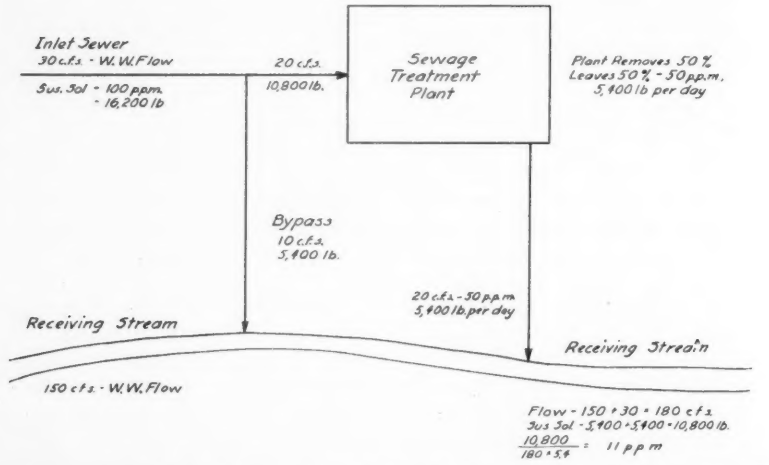
Inlet Sewer
30 c.f.s. - W.W. Flow
Sus. Sol - 100 p.p.m.
- 16,200 lb
20 c.f.s.
10,800 lb.
Sewage Treatment Plant
Plant Removes 50 %
Leaves 50 % - 50 p.p.m.,
5,400 lb per day
Bypass
10 c.f.s.
5,400 lb.
20 c.f.s. - 50 p.p.m.
5,400 lb. per day
Receiving Stream
Receiving Stream
150 c.f.s. - W.W. Flow
Flow - 150 + 30 = 180 c.f.s.
Sus Sol - 5,400 + 5,400 = 10,800 lb.
10,800 / 180 * 5.4 = 11 p.p.m

FIGURE 2.—Illustration of suspended solids loading of stream receiving effluent from a primary treatment plant under wet weather flow conditions.

sewage flow, with the same amount of suspended solids (16,200 lb. per day), but in a concentration of only 100 p.p.m. With a primary sewage treatment plant designed to handle the total flow of double the average dry weather flow or, in this case, 20 c.f.s., it is necessary to bypass the excess of 10 c.f.s. to the stream without treatment. The sewage treatment plant, being somewhat overloaded, is not as efficient in this case as it would be when handling only dry weather flow, and the removal is figured at only 50 per cent, with 50 per cent going out the effluent sewer. This means then that the effluent sewer carries 50 p.p.m. or 5,400 lb. per day of suspended solids, and the bypass sewer, carrying 10 c.f.s., likewise carries 5,400 lb. per day. This results in a total of 10,800 lb. of suspended solids to the stream which has a total flow of

180 c.f.s. The resulting concentration of suspended solids in the stream is 11 p.p.m., the same as obtained during the dry weather flow illustrated in Figure 1.

Figure 3 shows a receiving stream with a dry weather flow of 50 c.f.s., a sewer with 10 c.f.s. of dry weather flow and a B.O.D. concentration of 300 p.p.m., or 16,200 lb. per day. The sewage treatment plant removes 95 per cent of the B.O.D., the remaining 5 per cent or 815 lb. per day going to the stream. With the receiving stream flow of 60 c.f.s. and the B.O.D. load of 810 lb. per day, the concentration of B.O.D. in the stream becomes only 2.5 p.p.m.

Figure 4 shows the same stream at wet weather flow of 75 c.f.s., with a sewage flow of 30 c.f.s. containing 100 p.p.m. of B.O.D., or 16,200 lb. per day.

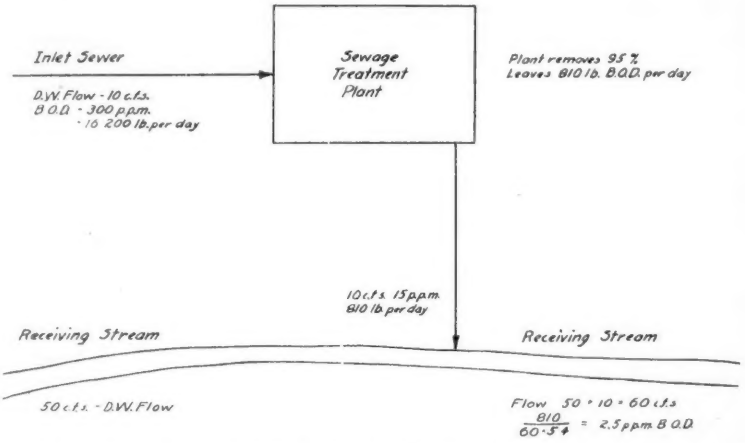
Inlet Sewer
D.W. Flow - 10 c.f.s.
B.O.D. - 300 p.p.m.
- 16 200 lb. per day
Sewage Treatment Plant
Plant removes 95 %
Leaves 810 lb. B.O.D. per day
10 c.f.s. 15 p.p.m.
810 lb per day
Receiving Stream
Receiving Stream
50 c.f.s. - D.W. Flow
Flow 50 + 10 = 60 c.f.s.
810 / 60 · 5.4 = 2.5 p.p.m. B.O.D.

FIGURE 3.—Illustration of B.O.D. loading of stream receiving effluent from a complete treatment plant under dry weather flow conditions.

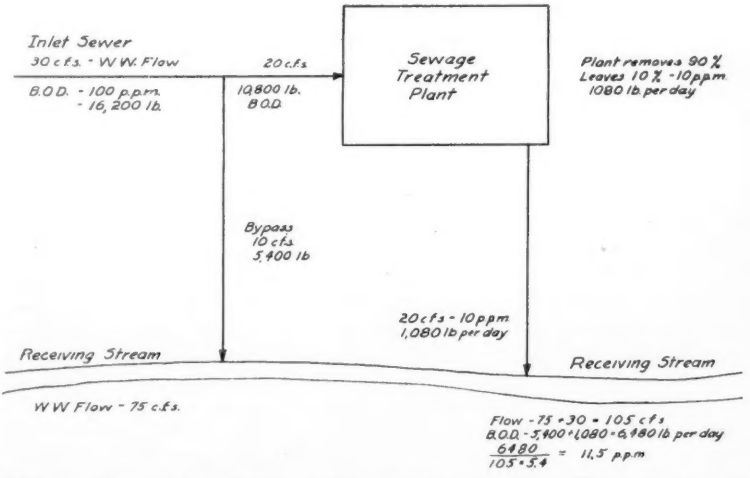

FIGURE 4.—Illustration of B.O.D. loading of stream receiving effluent from a complete treatment plant under wet weather flow conditions.

Twenty cubic feet per second of this flow is carried through the sewage treatment plant, which under this overloaded condition removes only 90 per cent of the B.O.D., leaving 10 per cent or 1,080 lb. per day to go to the stream. The bypass sewer would discharge 10 c.f.s. of untreated sewage containing 5,400 lb. per day of B.O.D. This results in a total daily B.O.D. load of 6,480 lb. to the receiving stream, equivalent to a concentration in the total flow of 105 c.f.s. or 11.5 p.p.m.

These four illustrations indicate what might be expected in primary treatment and complete treatment plants under dry weather and wet weather flow conditions, with certain assumptions made as to flows and concentrations. It appears that in consideration of primary treatment plants much more leeway is available in the amount of sewage bypassed and the amount treated than is possible in consideration of complete treatment plants where a higher degree of purification is required.

In the case of the primary treatment plant illustrated, the same concentration of suspended solids in the receiving stream is indicated under the dry weather flow condition and the wet weather flow condition, with a third of the sewage being bypassed at the latter time. In the case of the complete treatment plant, however, with a third of the flow bypassed under wet weather conditions, the B.O.D. of the receiving stream is four or five times as high as it would be under dry weather flow conditions.

Mr. Boyce's paper suggests the possibility that dilutions up to twenty times might be required in the case of a complete treatment plant. It would appear that something less than twenty times would be needed, but just how much dilution is required is a question for determination in any given local situation.

It should be pointed out that the illustrative figures given above for suspended solids and B.O.D. are based on a 24-hour flow of sewage. It is true that storms occur normally for shorter periods of time and the amount of pollution contributed to a stream by a storm of a shorter duration than 24 hours would be much less than is indicated in the above figures. This is another element which should be considered in any analysis of a sewage disposal problem.

Industrial Waste Complications

The second problem summarized in the paper has to do with the fact that industrial waste disposal needs more study and research. This need is urgent because of the rapid current development and expansion of industry. There are several ways that the problem can be handled.

In a recent study and survey made for a Michigan city which has enjoyed extensive industrial development, a solution of the problem was effected by the recommendation of individual waste treatment plants at each of the major industries. These plants will give a certain amount of treatment to the industrial wastes so that they can be discharged into the city sewer system without burdening the city treatment plant to any greater extent than is caused by ordinary domestic sewage. In another city it has been found practicable to combine the industrial waste from a tannery with the city sewage for treatment in one common plant. In this case the tannery waste is more easily handled when mixed with city sewage than if it were handled separately, and enough city sewage is present to offset the effect of the tannery waste. The domestic sewage flow here will be some three or four times the flow of tannery waste.

Another aspect of the industrial waste problem which makes it somewhat different from the problem of municipal sewage treatment is the fact that industrial processes and methods change quite frequently and exten-

sively. Such change in the amount and quality of industrial waste has been quite evident during the recent war years in many Michigan sewage treatment plants. By putting the responsibility for treatment of industrial wastes on the industry, the treatment becomes a part of the industrial process. Treatment costs can be figured into the manufacturer's production costs and methods can be changed from year to year as necessary to meet changes in the industrial processes. In this way the industrial waste problem can be handled much more easily and effectively than it can be if the wastes are merely dumped into a city sewer and the city assumes the responsibility of keeping up with the changes in industrial activity.

Critical Stream Conditions

The third item brought to attention by Mr. Boyce is the reminder that average results of sewage treatment are of no consequence as compared with those obtained during short periods of peak flow, minimum dilution, poisonous waste discharge, and the like. This is a truth that is sometimes overlooked by designers, but nevertheless is of fundamental importance. Certainly there are seasonal variations in stream flow which bring about varied conditions of pollution, and a plant which might be adequate to handle the sewage during a period of high stream flow might be found entirely inadequate in the late summer when the stream flow is at a minimum. Sewage treatment plant design standards, therefore, should insure satisfactory results under the worst conditions, with the assurance that under average or normal conditions the results will be better than are theoretically required.

In this respect it is sugggested that standards might be set up for the purity of receiving streams. In some places such standards have been established and have even gone so far as to designate a receiving stream as one whose best function is the disposal of sewage and industrial waste rather than that of recreation or public water supply or some other more refined use.

Consulting Engineer's Problem

A fourth aspect which the paper does not suggest, but which is of interest in any consideration of sewage collection and treatment, is that of the position of the designing or consulting engineer.

The consulting engineer must first satisfy his own concepts of the best solution of the problem, and then proceed according to his own standards of design to produce a workable plan for the solution of the problem at hand. After he has developed his solution of the problem, he must satisfy the requirements of the various governmental agencies that have the right of review and approval of his plan, such as the state health department, the stream control commission, and in some cases the Federal government. Finally, he must satisfy his client by submitting a workable plan which is within the means of the client to finance.

It is sometimes a difficult matter for the consulting engineer to work out a solution of a sewage disposal problem which will satisfy the various public agencies, if the client happens to be a city without means of financing the project. No amount of good engineering and argument and discussion will be of any avail if there is not enough money at hand to build a project and put it to use. Consequently, the consulting engineer is curbed to some extent by economic limitations in his ability to satisfy requirements of high standards of design.

Industrial Wastes

MILK WASTE TREATMENT AT THE DETROIT CREAMERY COMPANY CONDENSERY, OVID, MICHIGAN *

By Loring F. Oeming

Sanitary Engineer, Michigan Stream Control Commission, Lansing, Mich.

The waste treatment plant recently constructed by the Detroit Creamery Company at its Ovid, Mich., condensery is expected to correct a stream pollution problem of several years' standing.

Milk input to the factory is divided between the condensery unit and a Grade A milk receiving station. It operates on a widely varying production schedule depending upon the demands of the Detroit market for fluid milk and upon the market for its manufactured products. Milk intake ranges from 150,000 lb. per day during periods of low milk yield to about 500,000 lb. daily at flush periods. Of the total intake, between 50,000 and 450,000 lb. daily are processed in the condensery for the production of sweet cream, sweetened condensed skim milk, skim milk powder, ice cream mix and cottage cheese. The balance is shipped as fluid milk or is marketed as Grade A milk.

The waste discharges formerly flowed directly to the Maple River, where the natural flow during the critical summer months often falls as low as 5 c.f.s. for extended periods of time. The pollution effects of the milk wastes were reflected in exhaustion or severe depletion of dissolved oxygen for 6 miles below the outlet. Odor nuisances, destruction of fish life, and injury to agricultural interests through impairment of pasturage water for livestock resulted. From analyses of stream survey data it was found that proper stream protection would require the pollution loading to be reduced to 40 lb. per day in terms of 5-day B.O.D.

Surveys of the factory wastes were conducted by state authorities and also by an independent industry research organization. They established the basis for design of the treatment plant at 100,000 g.p.d. average flow of wastes containing 1,000 lb. of 5-day B.O.D. Cheese whey was not included, as a satisfactory method of disposal had been found by dumping to an abandoned gravel pit. Disposal of whey as a by-product for manufacture into animal food was tried, but was not acceptable to the company. Attempts to reduce waste loadings further by institution of waste saving methods were not productive.

Vacuum pan water was found to contribute 10 lb. of 5-day B.O.D. daily. The company elected to continue discharging this flow directly to the stream, and to deduct this B.O.D. contribution from the allowable load. The treatment process, therefore, was required to produce an effluent limited to 30 lb. of B.O.D. daily.

The process selected consists of biological filtration in two stages with recirculation and high rates of application. Plans were completed in May, 1945, but numerous obstacles prevented completion of the plant until October,

* One of a series of special contributions by members of the FSWA Committee on Industrial Wastes.

1947. The project failed to qualify for War Production Board approval in 1945. Again, in May, 1946, authority to undertake construction was denied by the Civilian Production Administration. Upon further review in June, 1946, the application was approved and construction started. Further delays were encountered due to material and equipment shortages.

Unique Design

The plant (Figure 1) represents a departure from conventional design practice in some respects and incorporates unusual and novel features.

In order to secure isolation from nearby dwellings, a site was located some 3,000 ft. from the condensery. The wastes are conveyed to this site through a 15-in. vitrified pipe gravity sewer, including a river crossing by means of a syphon.

The principal plant units are a pumping station containing a bar screen, waste pumps and controls necessary for recirculation, primary and secondary clarifiers, primary and secondary filters and a sludge digestion tank.

The pumping station is 24 ft. in diameter, with the wet well divided

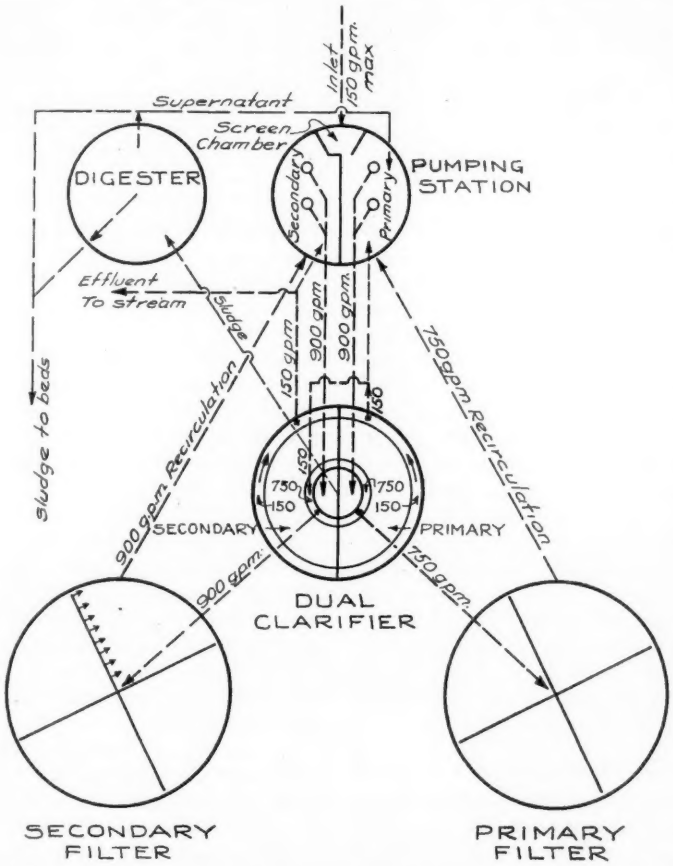

FIGURE 1.—Flow diagram of milk waste treatment plant at Detroit Creamery Company condensery, Ovid, Mich.

into two compartments. One compartment receives the raw waste and recirculated flow from the primary filter. The other receives the effluent from the primary filter and the return flow from the secondary filter. Pumping equipment consists of four pumps, each having a capacity of 450 gal. per minute. Two pumps take suction from the primary and two from the secondary wet well.

Primary and secondary settling is accomplished in one circular tank 24 ft. in diameter with a 12-ft. side water depth. A curtain wall across the diameter extends 7 ft. 6 in. below the water surface, separating the primary from the secondary side; but an opening is left at the bottom of the tank for the sludge scraper mechanism. Consequently, primary and secondary sludges intermix in the sludge outlet hopper.

Both primary and secondary filters are 65 ft. inside diameter with a 4-ft. depth of media. Original plans called for blast furnace slag, but due to difficulty in obtaining proper sizes only part of the secondary filter contains slag. Rock 2½ in. to 4 in. in size was used to complete both beds. Underdrains are of vitrified block, and are vented at the surface of the beds by means of vitrified pipe risers placed along the periphery at 10-ft. intervals. Four-arm, reaction type, rotary distributors apply the waste to the beds.

The digester is a fixed-cover, circular concrete tank 24 ft. in diameter and 12 ft. deep. No heat is provided. Supernatant liquor is returned to the primary pump well. Ample capacity for sludge disposal is provided by underdrained sand beds and by a gravel pit at the plant site.

Operation Features

In operation of the process, waste flows pass through a bar screen and over a weir to the primary suction well. Pump selection is controlled from electrodes on the upstream side of the weir. At raw waste inflow rates up to 75 g.p.m., one 450 g.p.m. pump operates in the primary and another in the secondary side of the wet well. The second set of pumps comes into service and all four operate at inflow rates between 75 g.p.m. and the expected 150 g.p.m. maximum. The difference between the two pumping rates and the rate of raw waste inflow is made up by return of primary and secondary filter effluent.

Distribution of the wastes is accomplished in a control chamber located in the center section of the clarifier (Figure 2). With the pumps discharging 900 g.p.m., the primary filter receives 750 g.p.m. from an inner overflow weir located near the center of the primary tank. This 900 g.p.m. is composed of 150 g.p.m. raw waste and 750 g.p.m. of primary filter effluent recirculated to the primary wet well. The 150 g.p.m. representing the difference between the pumping rate and the rate of discharge to the primary filter traverses the primary side of the settling tank to a peripheral weir and channel, from which it enters the control weir chamber on the secondary side of the clarifier. At this point it joins the 900 g.p.m. discharged from the secondary wet well. The total of the two, or 1,050 g.p.m., is then again divided, with 900 g.p.m. going to the second-stage filter from the inner weir in the secondary side of the clarifier, and the 150 g.p.m. traversing this side of the clarifier being withdrawn over a peripheral weir to the final effluent channel and outlet sewer. The 900 g.p.m. applied to the second-stage filter is returned to the secondary side of the pumping station for recirculation as above noted.

To provide automatic operation with raw waste flows less than 150 g.p.m., a connection is provided whereby a portion of the primary clarifier effluent can be diverted back to the primary wet well. The rate of return is controlled by a float-operated

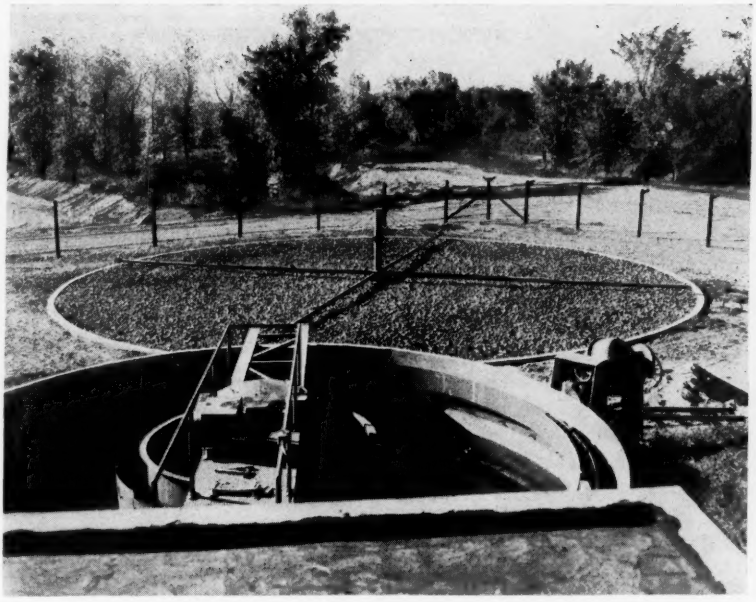

FIGURE 2.—Milk waste treatment plant, Ovid, Mich. Combination primary and secondary clarifier in foreground; secondary filter at rear.

valve, actuated by the water level in the primary wet well. A like arrangement diverts portions of the final effluent to the secondary wet well.

When inflow rates are such as to require operation of only one pump on each side, the system operates the same as outlined above, but at one-half the rates. Thus, the minimum recirculation ratio with one or both pumps operating will be about five to one, within the volumetric load limits of the plant.

The final effluent is discharged to Maple River by way of an open ditch some 1,500 ft. long. The outfall is constructed in porous soil and, during the first month of operation, all of the flow percolated into the ground, none reaching the stream.

The plant was placed in operation late in October. It was started with water introduced from the river. At the end of the first week, the flow was made up of 25 per cent waste and 75 per cent river water. Over the course of 6 weeks, the proportion of waste to river water was steadily increased until the full load was applied. However, the onset of cold weather impeded the conditioning of the filters and no data are available at present to indicate what performance will be obtained.

Acknowledgments

The sewers and treatment plant were designed for the Detroit Creamery Company by Hubbell, Roth and Clark, consulting engineers of Detroit, using a basic design prepared by Dr. H. A. Trebler of Sealtest, Inc., Research Laboratories. The combination primary and secondary clarifier design is covered by a patent issued to Dr. Trebler.

FODDER YEAST PRODUCTION FROM SULFITE WASTE LIQUOR

By Richard G. Tyler and William Maske

Respectively, Professor of Sanitary Engineering, University of Washington, In Charge of Disposal Project, Pulp Mills Research; and Associate Research Chemist, Pulp Mills Research

Two years of experience in operating ten laboratory scale high-rate trickling filters (1) for treating sulfite waste liquor convinced the authors that the flora which had developed at pH 3 from soil seeding, consisting of several types of yeast, could be grown more effectively in a different type of apparatus. The principal requirement was to provide the exceedingly large quantity of air required for rapid yeast propagation. It seemed possible that improved B.O.D. removals might also be secured over that obtained with the same organisms in trickling filters by eliminating the accumulation of molds which, on dying, greatly increased the B.O.D. of the filter effluent. With 3 per cent of sugar present in the liquor, a yeast yield might be anticipated that would provide an income that would defray the cost of the treatment process either wholly or in part.

Preliminary Concepts

The data concerning German research in this field were not available to the authors at the beginning of this research and the approach used was a natural outgrowth from the work on high-rate filters. The same 6-ft. lengths of 2½-in. plastic tubing were utilized for yeast propagators as had been used for filters, but were soon abandoned and a 16-ft. length of 4-in. plastic used to accommodate the large amount of foam produced. Air was fed through ¾-in. spherical aloxite air diffusers at the bottom of the tube.

Large quantities of foam were thus produced, which at first was looked upon as replacing the crushed stone of the filter. The liquor was also recirculated as in the filter, by pumping from the bottom of the tube and discharging over the top of the foam column. It later developed that this concept of the operation of the yeast propagator with recirculation of the liquor considerably accelerated the progress in developing its present effectiveness. In fact, the apparatus was at first referred to as a foam filter because of the similarity of operation.

There were several advantages in thus substituting the foam for crushed stone as filter media. The much greater surface of contact between the liquor and the air increased the oxidation effectiveness immensely. Also, trouble from clogging, experienced so frequently within the filters, was naturally non-existent in the foam column.

The various steps in the evolution of the presently used apparatus and methods are of no particular interest except in indicating the difficulties encountered and the methods developed for overcoming them. It should be noted, however, that yeast propagation with diffuser aeration is extremely sensitive to variations in any of its detailed operations, but an essential feature of any propagator is that it must operate continuously with a high degree of stability if it is to provide a practical means either for producing yeast or providing a method of partial disposal of sulfite waste liquor.

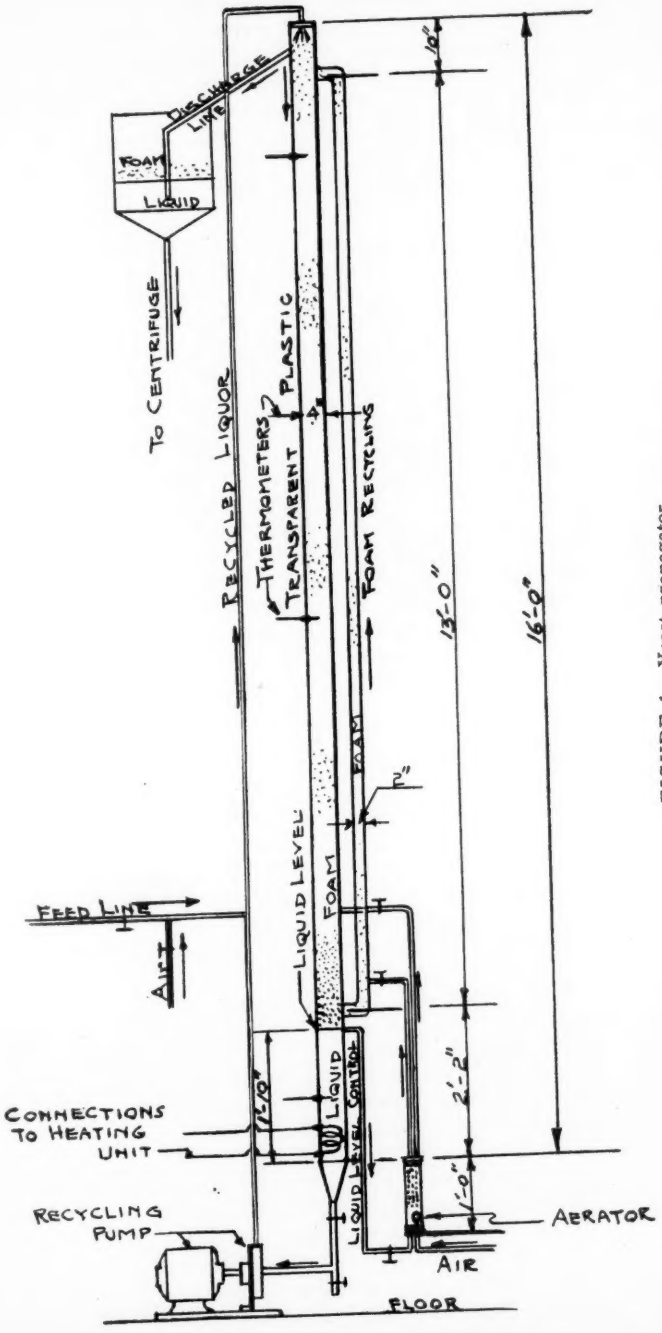

FIGURE 1.—Yeast propagator.

The development of adequate controls for each step in the process receives the major part of the researchers' time. In fact, successful yeast propagation requires that the problem of controls be solved and relatively stable operation be secured before a satisfactory study of the relationships among the variables can be made. The apparatus illustrated in Figure 1 has been operating continuously for some months with satisfactory stability as is indicated by the test data in Table I.

It should be noted that two types of aeration are being used in growing yeast on sulfite waste liquor, as is the case with activated sludge plants. This paper discusses results obtained using air diffusers. The other method utilizes mechanical aeration, which produces an air-liquor emulsion, is more efficient, and produces somewhat higher percentage removals of B.O.D. than does bubble aeration. It is believed, however, that a record of this research on bubble aeration will be of interest because of the scarcity of published data on yeast production.

Description of Propagator

The yeast propagator consists primarily of a 4-in. diameter plastic tube (cellulose nitrate) 16 ft. long. A funnel shaped bottom permits easier withdrawal of material by the recirculating pump and facilitates the emptying of the tube. A stainless steel recirculating pump discharges the liquor over the foam at the top of the tube.

Since the pump could not operate against the head produced by the height of the column and the frictional resistance to the flow through small tubes, air was fed into the discharge line, as shown in the illustration. This air flow served as a booster pump and at the same time provided a simple method for controlling the amount of recirculated liquor by varying the quantity of air used, rather than by throttling a valve on the pump discharge line. On small laboratory apparatus, throttled valves are always a source of trouble from clogging by micro-organisms or by the sulfite waste liquor itself. This air line was also utilized for feeding the liquor to the unit, thus eliminating the need for an additional pump for this purpose. Another satisfactory point for feeding the propagator would be the suction to the recycling pump. Air pressure on the liquor supply container aided in securing a positive flow of influent liquor.

Two aerators were originally located in the lower end of the propagator, which devices kept the yeast from settling while at the same time producing the foam that is so essential to the efficient operation of the process. These aerators consisted of one aloxite air diffuser and one 8-mm. glass tube. The height of the foam column was regulated by varying the proportion of air fed through the diffuser, and by varying the rate of recirculation of the liquor. The larger bubbles from the tube helped break the foam and control its height within the limits permitted by the propagator, which was 16-ft., the total available head room. Possibly 25 or even 30 ft. would be more desirable since it would facilitate the control of the foam column and increase the proportion of diffused air and the time of contact with the liquor, and would also decrease the recirculation rate for any given length of contact.

On first starting a run, the desired quantity of liquor (which has been previously steam-stripped) is placed in the propagator and seeded with an innoculum prepared by growing the yeast for a day or two in flasks on a shaking machine. The unit is then operated batch-wise for one or two days to develop a sufficiently large yeast population before starting continuous operation. Optimum operating conditions apparently require that the column have a liquor depth of 10 or 15 per cent of the total column

TABLE I.—Operating Data for Yeast Propagator

Date (1947)	pH	Daily Input			Air Input (ml. per min.)			Rate of Recirculation (ml. per min.)	Foam Density	Detention Time (hr.)	No. of Times Recirculated	Yeast (gm./l.)	Reducing Sugars			Grams Yeast per Gram of Used Sugars
		SWL (liters)	NH_4OH (ml.)	K_2HPO_4 (gm.)	Main Aerator	Diffuser Aerator	Total						Influent (gm./l.)	Effluent (gm./l.)	Per Cent Utilized	
March 6	3.90	12	36	3	3,350	440	3,790	280	0.180	18.7	35.4	10.24	31.2	7.4	76.3	0.430
March 7	3.88	16	48	4	3,350	440	3,790	280	0.180	13.3	26.3	9.34	31.2	11.3	63.8	0.469
March 10	3.93	20	50	5	3,750	440	4,190	280	0.168	9.50	20.2	8.94	30.2	10.4	66.7	0.430
March 11	3.82	20	50	5	3,750	440	4,190	280	0.180	9.83	20.2	9.57	30.2	10.2	67.3	0.456
March 12	3.80	20	50	5	3,750	440	4,190	280	0.180	10.65	20.2	8.99	30.2	7.6	74.8	0.398
March 13	3.82	20	50	5	3,750	440	4,190	280	0.180	10.85	20.2	9.72	30.2	7.4	75.5	0.426
March 14	3.84	20	50	5	3,750	440	4,190	280	0.180	10.23	20.2	10.40	30.2	7.5	75.1	0.459
March 15	3.82	20	50	5	3,750	440	4,190	280	0.180	10.23	20.2	10.37	30.2	7.3	75.9	0.450
March 24	3.84	20	45	5	3,750	450	4,200	300	0.192	6.06	21.6	9.37	30.4	8.9	70.3	0.436
March 25	3.82	20	45	5	3,750	450	4,200	300	0.168	9.40	21.6	10.40	30.4	7.2	76.3	0.448
March 26	3.80	20	45	5	3,750	450	4,200	300	0.180	13.02	21.6	10.44	30.4	7.1	76.7	0.439
March 27	3.82	20	45	5	3,750	450	4,200	300	0.192	9.34	21.6	9.48	30.4	9.2	69.7	0.447
March 28	3.81	20	45	5	3,750	450	4,200	300	0.180	6.06	21.6	10.15	30.4	7.5	75.3	0.446
March 31	3.82	20	45	5	3,750	450	4,200	300	0.192	10.46	21.6	10.48	30.4	7.1	76.7	0.450
April 1	3.83	20	45	5	3,750	450	4,200	300	0.180	10.43	21.6	10.45	30.4	7.0	77.0	0.447
April 2	3.81	20	45	5	3,750	450	4,200	300	0.192	11.15	21.6	10.48	30.4	7.2	76.3	0.452

height while the remaining volume is occupied by the foam. The density of yeast growth normally is greatest in the liquor, decreasing in the foam column with the minimum density at the top. The relative yeast densities vary with operating conditions. Recirculation of both the liquor and the foam was found useful in obtaining efficient operation.

Recirculation of the foam through the 2-in tube shown attached to the side of the propagator aids in securing greater uniformity of yeast population throughout the foam column. The continuous discharge of liquor over the foam furnishes an adequate food supply for the yeast, returns yeast from the liquid phase, where it tends to accumulate, to the foam for further oxygen supply, and breaks up the foam, washing it downward counter-current to the rising air bubbles. The foam in the 4-in. tube is heavier than that in the 2-in. tube because of its greater liquor content, and its greater weight causes the foam in the side tube to flow in an upward direction. Should this motion be too sluggish, an air intake from the aerator, shown in Figure 1, aids in its recirculation.

Some difficulty was encountered from clogging of the air diffuser, particularly when shutdowns occurred. For this reason, it was removed from the propagator and put in a 2-in. glass tube 12 in. in length, as shown in Figure 1. If clogging occurs, it requires only a few minutes for its removal and cleaning. This diffuser has been cleaned once a week to secure satisfactory operation. In a pilot plant, two diffuser units should be provided with one as a standby to place in service when the other is being cleaned.

Aeration

A major problem in growing yeast consists in supplying the large quantities of air required for their propagation. This quantity of air cannot be supplied to the sulfite waste liquor in a single application. It is necessary, therefore, to aerate at the maximum feasible rate, producing as much foam as can be kept under reasonable control, and to pass the liquor containing the yeast through the foam a sufficient number of times to secure the oxygen required for an adequate yeast yield.

The more important factors involved in this process include the area of air-liquor interface provided, the oxygen content of the air in the foam, and the time of contact between the organisms and the oxygen. To secure a maximum air-liquor interface, small bubbles are desired. The bubbles should not be too small, however, or more foam will be produced than can be controlled by reasonable rates of recirculation. An economic balance, therefore, must be struck between the advantage of increased oxygen absorption efficiency and the disadvantage of increased pumping costs.

As the organisms deplete the oxygen content of the air in the foam, it is necessary to break the latter and continually replace it with freshly produced foam. Foam breaking is accelerated by increasing the rate of recirculating the liquor, but is more difficult with dense foam produced by very small air bubbles. Recirculation also provides an increased time of contact between the organisms and the air in the foam. It is obvious, therefore, that the recirculation of the liquor is a very important part of this process.

In their efforts to produce yeast from sulfite waste liquor, the authors soon realized that all of the steps or parts of the total operation are interdependent and that the balance between them is a very sensitive one. A change made in one factor such as rate of aeration, affects others such as recirculation rate, liquid level in propagator, yeast yield, etc. Much time is required for setting up adequate controls so as to establish an appropriate stability of operation.

Table I gives the detailed test data for two 8-day periods of operation of

the propagator, and are typical of the results that have been obtained. Air efficiencies were determined from analyses of air entering and leaving the propagator to be 18.7 per cent. In other words, it has been necessary to supply approximately five times as much air as is theoretically required. Volumetric measurements of the applied air indicated air efficiencies as high as 30 per cent. This discrepancy has not been resolved as yet since tests to discover whether anaerobic action was also occurring have not clarified the matter. Even the smaller figure indicates a high air absorption efficiency when compared with that obtained in the sewage treatment field. In activated sludge plants, for example, efficiencies vary between 8 and 12 per cent.

Recirculation

The importance of recirculation has already been discussed. A few additional details, however, should be enumerated.

The number of recirculations that has been found desirable in the present research averages about twenty. With a greater length of foam column than is possible in the 16-ft. unit, a reduced number of cycles would probably suffice but pumping would be carried out against a greater head. It is also possible that in a deeper propagator there would be a maximum height beyond which the foam column would not build up. Fewer recirculations might be required, therefore, as control of the foam would not be a problem. The present research has not determined the length or height of foam column which will produce the maximum efficiency either from a standpoint of costs or of yeast production.

It has been found advantageous to recirculate both the liquor and the foam in the propagator. The liquor is pumped from the bottom of the propagator as indicated in Figure 1, and discharged over the top of the foam column. Since the yeast density is greater at the bottom of the foam column and decreases toward the top, it proved advantageous to recirculate the foam also, and this was done through the 2-in. glass tube shown at the right of the propagator.

Since the foam in the propagator is more dense than that in the recirculating column because of the added weight of liquor continuously passed down through it, the foam moves upward in the side column and is returned to the propagator near its top. The excess liquor on this foam drains back to the propagator, leaving a lighter foam. A connection from the aerator to the lower end of this column makes it possible to boost the flow rate of the recirculating foam if desired.

Discharge Rate

It is important to discharge the yeast from the propagator at a rate which does not exceed its growth rate, so that the yeast population in the unit will not be depleted and the propagator efficiency reduced. In securing this balance between the rate of yeast removal and that of yeast production, the selection of the point at which the effluent is drawn from the propagator is of prime importance. It would be advantageous to withdraw the effluent from the liquid phase and thus eliminate the handling of foam in the centrifuge receiving the effluent. However, since most of the yeast is in the liquor, it was found that too large a quantity of yeast was withdrawn with the effluent at this location.

Various locations in the foam column were tried for the withdrawal of effluent, but that presently used is near the top of the foam column as indicated in Figure 1. It is obvious that with a taller foam column or a different rate of recirculation, some other location might be more satisfactory.

It is possible, of course, to take the effluent from any desired point, as from

the liquid phase, and feed back to the propagator enough of the centrifuged yeast to secure maximum operating efficiency. This would increase the cost, however, so in the present research the yeast density in the propagator was controlled in the manner just described.

Detention Period

The detention period, or time of retention of the liquor in the propagator, varies with the height of the liquid level. It has been necessary, therefore, to find a means for controlling that level so as to maintain constant operating conditions. The liquid level is very sensitive to various factors in the operation, and its location also affects the efficiency of yeast production.

The control of the liquid level, however, was finally obtained by the simple device of having the liquor feed line from the propagator to the diffuser aerator take off at the desired liquor level. The aerator intake is made large enough to withdraw liquor faster than the maximum recirculation rate. As the liquor level drops, foam is drawn into the intake, its capacity is greatly decreased and the liquor tends to accumulate in the propagator from the recirculated material flowing downward over the foam. Thus the level is held very accurately at the desired point and is unaffected by wide ranges in recirculating rate.

The detention period is determined by dividing the total volume of liquor in the liquid and foam phases in the propagator by the rate of feed. This can be computed from the foam density which Table I shows to be about 19 per cent of the liquor density, which varies with aeration rate, size of bubble, recirculation rate, and yeast density. A simpler method is to read the equivalent depth of liquor on a piezometer taken off from the liquid phase.

An average detention period of about 10 hours for a feed rate of 20 liters per day was thus obtained. Computed on the basis of volume of propagator for convenient comparisons with filters, this represents a loading of 38 lb. B.O.D. per cu. yd. per day. It appears probable that little advantage, if any, would be secured by reducing this detention period to the shorter time reported by German workers. There is a definite job that has to be done and it can be accomplished efficiently by 10 hours detention with the propagator used and with the rates of aeration and recirculation recorded in Table I. Decreasing the detention period would necessitate increasing the recirculation and aeration rates, thus increasing the cost of production.

It is not claimed that the values reported for these factors as obtained in the present research are the optimum values for use in the design of a large scale unit. It is believed, however, that such designs should permit considerable flexibility in all factors so that a balance between them could be evolved which would secure a maximum economy for the particular design.

Yeast Production

Table I, which gives the essential data for two 8-day periods of operation of the propagator, shows that the average production of yeast under present operating conditions is about 8.7 grams per liter of sulfite waste liquor containing 30.4 grams per liter of reducing substances (herein referred to as sugars). Expressed in terms of the sugar utilized, this gives a yield of 0.44 grams of yeast per gram of sugar utilized. Flask experiments carried out on a shaking machine utilized 60 per cent of the total reducing substances and gave a yeast production of about 0.58 grams of yeast per gram of sugar utilized. In the propagator, 73.3 per cent of the total reducing sugars are being utilized.

With the propagator utilizing only 60 per cent of the sugars, the yeast production was about half of the weight of the utilized sugars. It is apparent, therefore, that conditions for securing maximum yeast yield are not the same as those for securing a maximum utilization of reducing sugars. Which of these operating criteria would govern on a full scale plant would depend upon whether the objective was to secure a maximum income through yeast production or to minimize the pollution produced in the stream receiving the discharge of the waste liquor.

B.O.D. removals have ranged between 35 and 50 per cent. This matter was discussed in greater detail in an earlier paper by one of the authors (2).

It should be pointed out that the high yeast-sugar ratio and yeast production per liter of sulfite waste liquor reported in Table I was obtained when mixed cultures of *Torula utilis* and the mycelial yeast isolated from the soil (1) were used. Test flasks seeded with pure cultures of *Torula utilis* gave lower yeast yields than when seeded with mixed cultures.

Separation and Drying of Yeast

Methods for the separation of yeast have been in use commercially for many years. The usual procedure of separating the yeast from the liquid phase is by centrifuging. The continuous, cream-type separator has proved satisfactory and can remove economically 95 to 97 per cent of the contained yeast. It is necessary to wash the sulfite waste liquor from the yeast and this can be done by suspending the yeast in water and again centrifuging it. One or two washes may be required.

Several methods of drying the washed yeast are in current use. Spray driers produce a fine powdery material while drum driers yield a flaky, more granular product which is preferred for mixing with stock feed. In the laboratory, vacuum drying and sublimation or low-temperature drying were used. Drying at high temperatures has produced discoloration and probably affects the vitamin content of the product.

Method of Determining Yeast Yield

Various methods were tried for making yeast yield determinations. The centrifuging of small quantities of material was troublesome and time-consuming. Methods for making cell counts were also not too simple nor rapid. After experimenting with these methods, it was found that, using a sample diluted to fifty times its own volume, it was easy and required a minimum of time to determine turbidities produced by the yeast in the diluted sample using a photo-electrometer for the purpose.

Checking results thus obtained against those secured by the centrifuge system gave a straight-line relationship. This method, therefore, has been in constant use with occasional checks with the centrifuge; it is rapid and has given very satisfactory results.

Characterization of Yeast

Prof. Joseph L. McCarthy * has done considerable work on the characterization of the yeast produced from sulfite waste liquor. He reports that the yeast contains approximately 50 per cent of protein, which would make it acceptable as a source of nitrogen for the preparation of stock feed. He found also that the yeast contained vitamins of the B complex.

Specifically, his tests indicate the presence of nicotinic acid, pantothenic acid and riboflavin, arranged in order of the quantity found. Feeding experiments with rats and chickens indicate that the yeast can be used as a protein source and is not toxic.

---

* In Charge of Utilization Project, Pulp Mills Research, University of Washington.

Cost Estimates

An estimate of the cost of growing yeast based on the operation of this laboratory scale propagator should not be taken too seriously for predicting costs for plants of commercial scale. However, it is of interest in indicating the relative cost of the various operations involved.

For example, with an indicated total operating cost for the propagator of $17.78 per ton, or 0.89 cents per pound of yeast produced, the expenditure for nutrients was the major item at $8.95 per ton of yeast, while the centrifuging, washing and drying of the yeast cost $6.75 per ton. The pumping and aeration cost was only $2.08 per ton. These represented 50.3, 38.0 and 11.7 per cent respectively, of the propagator operating cost.

Obviously any saving in nutrients or improvement in yeast drying and handling will have a greater effect on production costs than will corresponding reductions in cost of recirculating the liquor or improvements in air absorption efficiencies. These figures, therefore, call attention to those operations where further research may be most profitable. In the present research, attention had been focused on reducing pumping and aeration costs, with very little attempt to save nutrients.

Estimating the cost of plant, labor, power, marketing, etc., from this small laboratory scale unit indicates also that it should be possible to produce yeast with a propagator of similar design for about 3 cents per pound. This figure is made up of a capital cost of 21.0 per cent, a labor cost of 32.3 per cent, propagator operation cost of 29.9 per cent, and an assumed marketing cost of 16.8 per cent. It is recognized that this cost is below the figure quoted from the German experience but the apparatus and operation are simpler (for example, the foam breaker is eliminated) and stainless steel will not be required except for centrifuges, certain pipes, valves, etc. However, doubling the capital cost would add only 0.63 cents per pound to the total yeast cost.

The authors' purpose in attempting a rough cost estimate on the basis of the present research is two-fold. In the first place, they believe yeast can be produced more cheaply than is generally considered possible. Also, they found that they had originally placed the emphasis on factors generally found of major importance in the economics of sewage treatment plant operation. As already indicated, the estimate showed that these were not the items of major importance. The above estimates have been included, therefore, to serve these two purposes, with the hope that they may be of use to other researchers.

References

1. Tyler, Richard G., Maske, Wm., and Brewer, Robt., "Treatment of Sulfite Waste Liquor on High Rate Trickling Filters." THIS JOURNAL, **18**, 1155 (Nov., 1946).

2. Tyler, Richard G., "Effect of Alcoholic Fermentation and Growing of Fodder Yeast on Sulfite Waste Liquor." *Ibid.*, **19**, 70 (Jan., 1947).

DISPOSAL OF VEGETABLE TANNING WASTES*

By Howard T. Reuning

Keystone Tanning and Glue Company, Ridgway, Pa.

The characteristics of the wastes resulting from the manufacture of leather will vary with the process employed and the type of product desired. Heavy leathers generally are tanned by the vegetable method and the wastes from this process have been considered to present the more difficult problem of disposal.

Characteristics and Volume of Wastes

The greater precentage of the waste volume from a tannery originates in the beam house and results from the soaking, liming, washing, and other operations to which the hides are subjected before the actual tanning can be accomplished (1) (2). The wastes from this department are strongly alkaline, greenish gray in color, and contain particles of hair, flesh, and lime in suspension. They are discharged both intermittently and continuously throughout the working day, and vary widely in concentration and volume.

The spent tanning waste is slightly acid, reddish brown in color, and high in dissolved organic and colloidal substances. This waste, although contributing only from 5 to 10 per cent to the total tannery waste volume, accounts for most of the color of the combined wastes and for approximately half of the oxygen demand (1). The spent soda and acid bleach solutions, although relatively small in volume, are strongly colored and high in demand for oxygen. The finishing operations account for a negligible quantity of spent polishing waste.

The combined waste volume from vegetable tanneries has been found to vary widely. The average plant (1), however, discharges from 6 to 8 gal. of waste, with a population equivalent in 5-day B.O.D. of 4.8, for each pound of raw hide processed. A representative analysis of the combined wastes will approximate the following:

Total Solids	7,000 p.p.m.
Volatile Solids	3,500 p.p.m.
Suspended Solids	2,500 p.p.m.
Settleable Solids	8%
B.O.D. (5-day)	1,200 p.p.m.
Color (A.P.H.A.)	3,500 p.p.m.
pH	11

Waste Treatment Methods

The discharge of the untreated wastes to a stream exerts a marked deoxygenating effect that may inhibit aquatic life. The water frequently is discolored, and the sludge banks formed as a result of the heavy suspended solids content not only present an unsightly appearance but also contribute further to oxygen depletion.

In order that the wastes may be improved sufficiently to allow for harmless assimilation by the stream, or conditioned for inclusion with domestic sewage, it is essential that the suspended material be removed, together with as many of the dissolved solids as possible.

The literature (3) contains numerous references to individual and group studies that have been made in an effort to develop an efficient and practical method to accomplish this objective.

* Presented at First Annual Meeting, West Virginia Sewage and Industrial Wastes Assn., Bluefield, W. Va., October 1–3, 1947.

The Tannery Waste Disposal Committee of Pennsylvania, composed of representatives from the Sanitary Water Board and the leather industry of the Commonwealth, conducted an intensive survey of the problem from 1924–30 (2). These studies involved not only laboratory research but also the operation of two full-scale experimental treatment plants. Processes of treatment were developed in successive steps, with each step providing an additional measure of improvement. The recommended plan consisted of a general mixture of all wastes, sedimentation, primary filtration, chemical coagulation, secondary filtration, and uniform discharge of final effluent over a 24-hour period.

The first step, involving mixture and primary sedimentation, will remove 80 to 90 per cent of the suspended solids and from 40 to 50 per cent of the 5-day B.O.D. The complete treatment will eliminate almost entirely the suspended solids and effect about 90 per cent reduction in B.O.D. The cost of the additional treatment, however, is not commensurate with the further improvement obtained.

In the practical application of these principles (4) it has been found that a generally acceptable scheme of treatment can be provided through efficient primary sedimentation of all wastes except the spent tan liquors, resettlement, and uniform discharge of final effluent. The effectiveness of these measures in stream protection will be equivalent to the reductions obtained from the complete treatment outlined above.

The spent tanning liquors are relatively small in volume and can be evaporated. This procedure, however, is expensive and a limited market is presently available for the final product. Many tanneries provide sufficient lagooned areas to allow for routine storage of all liquor and release to the stream only at controlled rates during high stages. The additional dilution available at these times permits of harmless assimilation.

Design Factors

The design of a treatment works for a particular tannery will be influenced by a number of factors including the physical location of the plant, volume of wastes, availability of land, size and type of receiving stream, and the degree of treatment required by existing regulations. A careful appraisal of these factors is essential in the selection of treatment units that not only will prove effective but which also can be operated at minimum expense. Particular attention should be given to the possibility of reduction in waste volume through elimination of wastage and the bypassing or reuse of the relatively clean flow from the green stock pools and hair washer.

Screening

At the average tannery it will be necessary to pump the wastes to the treatment plant. A collecting sump, situated where all wastes can be delivered to it by gravity, should be provided. Horizontal or vertical centrifugal sewage trash pumps, float controlled for automatic operation, are relatively trouble free. The installation of two pumps, each capable of handling the average daily volume, will insure uninterrupted operation. Screening of the raw wastes generally is effective for removal of rope and the heavier solids in the raw wastes that frequently tend to clog the pumps. Rotary drum-type screens have been found quite satisfactory for this purpose and should be installed in the main sewer at the sump.

Primary Sedimentation

Units for primary sedimentation may consist of earthen basins or tanks constructed of concrete, wood, or steel, and operated on either the "flowing-through" or "fill-and-draw" principle.

The efficiency of either method in removal of settleable material is quite comparable under similar design conditions. The use of mechanical equipment to facilitate mixing of the wastes and removal of sludge has been found practicable at a number of plants.

In an installation of this type, the wastes would be pumped first to a mixing tank having a capacity equal to the maximum hourly inflow and equipped with paddle mixers operating at a slow peripheral speed. The mixed wastes would flow to a settling tank designed to provide a minimum theoretical detention period of 6 to 8 hours. The wastes should be introduced through submerged inlets distributed across the end of the tank. The effluent weir should extend the full width of the opposite end of the tank. The sludge collecting mechanism can be of standard sewage plant design but should provide for longitudinal and cross collection to a single withdrawal point. The sludge will flow readily under a low hydrostatic head or can be removed with centrifugal pumps.

In "fill-and-draw" primary sedimentation, a minimum of two units should be provided, each unit to have a capacity equal to the total daily waste volume, plus 50 per cent for sludge storage. Horizontal, float-supported, perforated pipes can be used to withdraw the settled effluent. The units should be located so that the sludge will flow by gravity to the outlets with a minimum of hand labor. The sludge must be removed at regular intervals to maintain good efficiency.

The effluent from either method of sedimentation should be resettled prior to discharge to a stream. A single tank or basin, with a capacity equal to one and one-half times the daily waste volume, can serve as a combined resettlement and flow equalization unit. The final effluent should be withdrawn through float-supported collector pipes to a control box equipped with a quick-acting valve. The discharge to the stream should be at a uniform rate over the 24-hour period.

Sludge Disposal

The disposal of sludge is a difficult and expensive problem at any tannery. The average daily quantity (1, 2) amounts to approximately 8 per cent of the waste volume, with a moisture content ranging from 95 to 98 per cent. Where ample land area is available the sludge may be stored indefinitely in large lagoons. In semirestricted areas, shallow drying beds are practicable. A series of beds, to provide approximately 2 sq. ft. of surface area for each pound of raw hide processed, would be required. The beds should be used in rotation and top water removed to facilitate drying. The sludge will dry readily to 80 or 85 per cent moisture content and can be removed satisfactorily with a power shovel and trucks. Centrifugal dewatering (5) will reduce the sludge volume from 80 to 90 per cent and is a practical, although expensive, solution for those plants located in closely builtup sections.

The individual nature of any problem in tannery waste disposal precludes more than a brief outline of the general measures adaptable in the treatment of the process waters. A thorough study of all phases of the problem is essential to the design of a treatment works that will produce an effluent which can be assimilated harmlessly by the stream.

Paw Paw Tannery Treatment Plant

The Keystone Tanning and Glue Company at the present time is constructing new waste treatment facilities at its Paw Paw, W. Va., tannery. This plant produces heavy leather by the vegetable process and discharges approximately 200,000 gal. of waste each working day. The wastes currently flow to two dyked areas, operated as flowing-through units, which

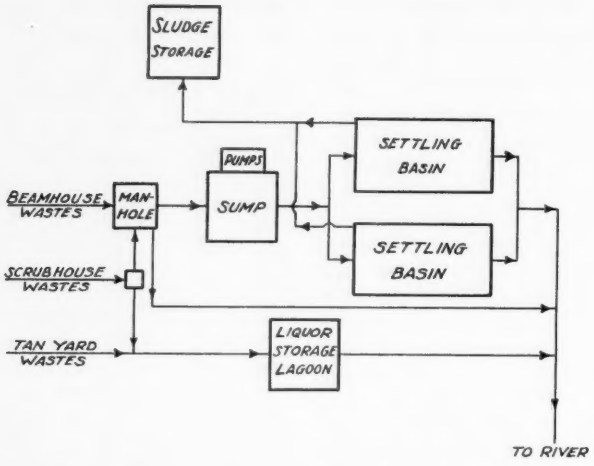

FIGURE 1.—Flow diagram of waste treatment plant being constructed by the Keystone Tanning and Glue Company, Paw Paw, W. Va.

provide sedimentation and sludge storage. The effluent is released at controlled rates to the Potomac River over the 24-hour period.

The new facilities will consist of the following principal units: collecting sump, pumping station, two earthen settling basins, sludge storage area, and spent tan liquor lagoon (Figure I). Essential equipment appurtenant to these units includes waste and sludge transmission lines, sewers, and discharge control apparatus. Treatment will involve collection, sedimentation, and flow equalization of settled effluent for all wastes except the spent tan liquor. This waste will be discharged routinely to the storage lagoon and released only during periods of elevated stream stages. The scrub house wastes can be diverted to this lagoon if complete removal of color from the normal plant effluent should prove desirable at times of drought flow.

The treatment works will be operated regularly in the following manner: All wastes from the beam house and scrub house will be collected in trunk sewers and conveyed by gravity to the sump. Two float-controlled, motor-driven, horizontal centrifugal pumps, located in the adjoining dry well and each capable of delivering 500 g.p.m. against a total head of 27 ft., will be used to pump the wastes to the settling basins. One pump will handle the incoming flow at all times except during peak discharge periods, when the second pump will provide the additional capacity required.

Each settling basin is 200 ft. long by 60 ft. wide and has a maximum available capacity of 500,000 gallons. They will be operated alternately as fill-and-draw units, the clarified effluent in one basin to be withdrawn over a 24-hour period while the parallel basin receives the incoming raw wastes.

Horizontal, swinging, drawdown pipes for collection of effluent will be float-supported to insure removal of the clearest liquid near the surface of the basin at any existing level. Permanent supports under the collector pipes, extending above the maximum sludge level, will prevent withdrawal of any portion of the solid residue. An orifice box and float-actuated valve will provide the necessary regulation of flow. Each basin will provide a

minimum detention period of from 10 to 12 hours, exclusive of an allowance of 100,000 gal. per basin for sludge accumulation.

The basins have been constructed with a 1.5 per cent slope from effluent to influent end, the deeper portions being located at the latter point to provide the additional capacity for the heavier sludge that will be deposited immediately. Sludge will be removed through openings located at points of lowest elevation and will be conveyed by gravity to a storage area located nearby. This area will provide sufficient capacity for indefinite retention.

The lagoon for spent tan liquors has a capacity of 3,000,000 gal., which will provide storage for a minimum of 200 operating days. Stream flow records indicate that the yearly discharge is more than ample to provide a dilution of at least 1 to 50,000, which is adequate to prevent any discoloration or dissolved oxygen depletion.

The routine plant effluent should contain an average of less than 0.3 per cent settleable solids and have a suspended solids value of approximately 350 parts per million. The 5-day B.O.D. should not exceed 375 parts per million. The raw wastes at this tannery are similar in characteristics to those of a typical plant using the vegetable process. Based on accepted analytical data, reductions of 96 per cent, 81 per cent, and 69 per cent in settleable solids, suspended solids, and B.O.D., respectively, should be attained from sedimentation. Uniform distribution of flow to the stream over the 24-hour period will be equivalent in effectiveness to greater plant reductions than would be indicated.

References

1. "An Industrial Waste Guide to the Tannery Industry." Appendix "XI" of Supplement "D," Final Report to the Ohio River Committee. U. S. Public Health Service (1942).
2. "Treatment of Tannery Wastes." Pennsylvania Department of Health (1930).
3. "Report of Stream Pollution Committee." II. Abstracts of Papers on Tannery Waste Treatment. *J. A. L. C. A.*, **39**, 378 (1944).
4. Milligan, F. B., "Tannery Waste Treatment in Pennsylvania." *The American City* (Feb., 1938).
5. "An Effective Tannery Waste Treatment Plant." *Public Works Magazine*, **78**, 3, 21 (1947).

MAKE YOUR HOTEL RESERVATIONS FOR THE DETROIT CONVENTION

The Hotel Statler at Detroit, headquarters for the Twenty-First Annual Meeting of the Federation in October, will be able to accommodate most of the out-of-town registrants. Some rooms will also be made available by the Book-Cadillac Hotel, located about three blocks from the Statler.

Requests for room reservations should be addressed directly to the hotel. Note that the technical program will open on Monday morning, October 18, and will close at noon on Thursday, October 21.

WRITE NOW FOR YOUR RESERVATIONS!

PRETREATMENT OF CARBOHYDRATE INDUSTRIAL WASTES *

By Frederick G. Nelson

Manager, Pacific Coast Division, The Dorr Co.

It is impossible to cover all phases of the industrial waste problem in one discussion. The broad policy as to how waste treatment is to be financed, methods of treating the various types of wastes, and the degree and point of treatment are some of the phases which must be given special consideration.

The West Coast is probably more immediately concerned with the wastes from fruit, vegetable, and allied food processing plants, and those connected with the wine industry. Therefore, this discussion is limited to the treatment of those wastes which can generally be classified as carbonaceous, although many such wastes also contain nitrogenous matter and a variety of other materials. These wastes have similar characteristics to the extent that septic action starts quickly and that they yield readily to biological treatment, if handled properly.

Municipal Waste Problems

The nature of the industrial waste problem faced by many West Coast cities is well illustrated by the problem of Modesto, Calif. This municipality's population in 1944 was about 20,000, yet the population equivalent of its combined industrial waste and domestic sewage was approximately 220,000 persons.

The report by Hyde, Gray and Rawn (3), prepared in 1941 for the East Bay cities of California, gives population equivalents for wastes of various fruit packing plants, many of which are tributary to municipal sewer systems. Table I was prepared from data contained in this report. Population equivalents are shown on the basis of 0.104 lb. of 5-day B.O.D. per capita, which was the figure found to prevail for the East Bay cities, and also on the basis of 0.167 lb., which is the more common factor.

It is apparent that where canneries are located in small cities the domestic sewage load is insignificant compared to the industrial waste load during the canning season.

Pretreatment of Wastes

Pretreatment has a rather broad meaning and may cover anything from simple screening to a relatively high degree of oxidation. It is usually interpreted as refering to some method of treatment at the origin, although the waste may be carried to the city treatment plant and there given some form of pretreatment before being mixed with the city sewage.

Pretreatment is given for a variety of reasons, but usually to eliminate the possibility of damage to the sewer system, to prevent odors, or to eliminate the possibility of overloading the city sewage treatment plant or the receiving body of water.

It is well known that most carbonaceous wastes, if properly handled, yield readily to standard methods of sewage treatment. However, due to the high population equivalent of many industrial wastes, standard methods of sew-

* Presented at the 1946 Annual Meeting of the Pacific Northwest Sewage Works Assn., Gearhart, Ore., May 22, 1946.

TABLE I.—Fruit Packing Waste Characteristics

(Quantities Expressed per Ton of Fruit Packed)

Fruit Packing	Water (gal.)	5-day B.O.D. (lb.)	Suspended Solids (lb.)	Population Equivalent	
				At 0.104 lb. B.O.D. per Capita	At 0.167 lb. B.O.D. per Capita
Apricots (lye peeled)[1]	2,500	7.9	—	76	47
Apricots (no lye)[1]	2,500	4.2	5.4	40	25
Peaches[3]	2,700	56.8	13.4	550	340
Peaches[1]	2,600	29.2	13.0	280	175
Tomatoes (no skins or pulp)[2]	450	25.0	27.9	240	150
Tomatoes[1]	3,600	29.7	8.1	290	178
Pears (with trim)[3]	1,300	52.4	72.9	500	313
Pears (after $\frac{1}{8}$-in. screen)[3]	1,300	24.7	13.1	240	148

[1] J. H. Kimball and T. R. Gregory. THIS JOURNAL, 9, 4, 607–614 (1937). J. H. Kimball and T. R. Gregory. *Calif. Sewage Works Journal*, 9, 2, 27–34 (1937).

[2] Harry B. Hammon. U.S.P.H.S. Bul. No. 118 (1921).

[3] Peaches and pears canned in same plant. All wastes removed by water carriage. Pear peelings removed by $\frac{1}{8}$-in. slotted screen; both peach and pear waste finally screened through 10-mesh screen. Waste contains lye-peeler waste and fruit juices.

age treatment become expensive and may be beyond an industry's ability to pay. The problem is one of finding methods for speeding up these standard treatment processes.

Use of Screens

The type and degree of treatment must be determined for each problem. The minimum treatment is screening, with the size of the openings being determined by the nature of the wastes and their subsequent treatment or disposal.

Where screening is the only treatment given, it is desirable to use as small a mesh as practical without producing screenings which will be too wet to be readily carted away and disposed of in a sanitary manner. The ideal mesh for fruit and vegetable wastes has not been definitely determined, but it probably is in the range of 20 to 40 openings per inch.

Fine screens in most general use can be broadly classified into revolving and vibrating types. The North and Dorrco screens are typical of the revolving units, and the Link-Belt screen of the vibrating types.

There are two major items to consider in the selection of a fine screen:

(1) The method of handling screenings: If the water level in the waste line is at such an elevation that the screenings cannot be discharged directly to a bin or trucks, it is necessary to provide a screenings elevator or to lift the raw waste prior to screening. The former is the most satisfactory but probably the more expensive in first cost.

(2) The cost of installation: The first cost of the various types of screens, including installations, differs considerably, but generally the more expensive types have a longer life and result in less operating expense. They are generally indicated for plants operating a considerable portion of the year, where the time for upkeep of machinery is limited.

If wastes are to be given subsequent treatment, screening is included only for the purpose of removing particles which will cause operating difficulties in the following treatment units. Again, the proper size openings must be determined for the particular job.

If screens are followed by vacuum flotation or sedimentation, the openings may be ⅛ in. diameter or larger, unless the solids are to be digested in separate sludge digestion tanks where there is a possibility of encountering a scum problem.

Tomato wastes are an example where the skins and seeds do not digest but rather collect as a dense surface scum. Plant operators know that tomato seeds will germinate after several months digestion, which indicates that they can better be disposed of as screenings.

Except for very unusual circumstances, screening should be done at the industry's plant. It has the following advantages:

(1) it removes the solids before they have had an opportunity to become septic, so that they either can be utilized for stock food or can be disposed of in an inoffensive manner;

(2) it prevents building up deposits or stoppages in the sewers; and

(3) management has a better picture of what is being lost, and may find means of reducing the wastage.

Vacuum Flotation

Carbonaceous wastes have a tendency to form considerable scum in sedimentation tanks. This, no doubt, is due in part to septic action where the sugars decompose and produce gas which becomes attached to the suspended solids and tends to cause them to float. However, septic action does not seem to be the only cause of scum formation as it has been observed that some fruit wastes, particularly peaches, have floating solids while the wastes are still perfectly fresh. Because of this tendency to float, a high percentage of the suspended solids can be removed by vacuum flotation.

The principle of vacuum flotation is simple. It consists of entraining a gas in the liquid which is then subjected to a vacuum, causing the gas bubbles to increase in size and rise to the surface, bringing suspended solids with them.

In practice the wastes are subjected to a short period of aeration with 0.025 to 0.05 cu. ft. of air per gal. being added by an aerator designed for entrainment of gas in liquid. The wastes then pass to a compartment where the large bubbles of air escape; then directly to the holding tank where they are subjected to a vacuum equivalent to approximately 10 in. of mercury. Solids quickly rise to the surface forming a relatively dense mat. Mechanical skimmers move the scum to a separate compartment of the tank from which it is drawn by the conventional type of plunger sludge pump. The clarified waste discharges through ports into a launder located near the bottom of the tank, returning to the sewer.

Grit and other quick-settling solids drop to the bottom of the tank and are removed and either washed in a grit washer, with the putrescible solids being returned to the flow, or disposed of without washing.

Overflow rates from 5,000 to 10,000 gal. per sq. ft. per day have been used, with 5,000 to 7,000 being preferred for industrial wastes. Pilot plant work has shown no appreciable lowering in percentage removal for rates not exceeding 7,000 gallons.

Laboratory tests and one full size commercial installation have shown that 50 to 80 per cent of the suspended solids can be removed on peach or tomato wastes. Data is not available on other fruit and vegetable wastes, but good results could be expected except on wastes high in colloidal solids.

Vacuum flotation not only has the advantage of floating the solids which have a natural tendency to float, but the waste is detained for a much shorter period than in sedimentation tanks, and therefore less septic action takes place.

Sedimentation

With few exceptions, industrial wastes must be given some detention time for removal of settleable solids. Often it is desirable to provide this treatment at the source to prevent sludge deposits in the sewer system. Sedimentation is particularly important for wastes such as flume water from beet sugar plants and those from plants processing root crops, where considerable grit and other inorganic matter is present.

In some instances, tank treatment is all that is required prior to discharging the waste into the stream or other body of water. In such instances, it is desirable to provide treatment at the source rather than to carry the waste through the sewer system to the city treatment plant.

Sedimentation tanks are of the conventional designs, generally of the mechanically cleaned type, except for very small installations where plain hopper-bottomed tanks may be used. Septic tanks or Imhoff tanks are seldom used at the source because of the potential odor nuisance.

Detention time must be determined for each particular problem. As short a period as practical should be used in order to minimize septic action. Again referring to flume water from beet sugar plants, 1-hour detention is satisfactory because the solids settle quickly. An economical clarifier design was developed for these wastes in which the tank floor and sides are of earth. The only concrete required is for the center pier foundation for the sludge collection mechanism and for the piers supporting the effluent launder weir. The design is entirely satisfactory for wastes having settleable solids low in putrescible matter.

Disposal of Sludge

Use of either vacuum flotation or sedimentation at the source creates a sludge disposal problem. It must be studied for each individual job. The most generally used method has been to pump sludge to lagoons or to other waste land, such as abandoned gravel pits. This practice is satisfactory if there is no danger of an odor nuisance developing. For small plants it is practical to dispose of sludge by carting in tank trucks.

To date, very little has been done on digestion of industrial waste sludge at the site, but this method of treatment should be given more consideration. It offers a means of eliminating odors and possibly reducing operating costs. It is entirely possible that the value of the gas produced and the sale of sludge would be sufficient to cover the cost of digestion.

The argument generally advanced against the digestion of sludge at the source is the necessity of the industry providing trained operating personnel. The operation could be under the jurisdiction of the city and by the sewage treatment plant personnel, at a charge agreed upon the city and the industry.

Secondary Treatment

Activated sludge, as well as trickling filters, has been employed for secondary treatment for cannery and other carbohydrate wastes. Generally speaking, however, trickling filters are more satisfactory than activated sludge, for the following reasons:

(1) The B.O.D. is exerted rapidly, probably due to the high sugar content, and filters satisfy this demand much more quickly than does the activated sludge process.

(2) Trickling filters are known to have the ability to take considerable shock load, while the activated sludge process is thrown out of control if the overload persists for more than a few hours.

By applying the high-rate filter principle, employing recirculation,

loadings may be carried very high. Just how high will depend on the strength of the raw waste and the degree of treatment required. The pounds of 5-day B.O.D. removed per cubic yard of stone is a function of these two items. Where filters are to be used for pre-treatment only and for wastes averaging around 1,000 p.p.m. 5-day B.O.D., or greater, loadings may be carried to 5 or 6 lb. per cu. yd. of stone, or even greater.

Tests on the treatment of corn cannery wastes in the biofiltration plant at Plainview, Minn., showed 5-day B.O.D. loadings through the primary clarifier and primary filter as high as 22 lb. per cu. yd. of stone, with a reduction of approximately 50 per cent. The B.O.D. of the raw wastes averaged around 8,400 p.p.m. Ponding of the stone did not occur, but septic action tended to develop in the primary clarifier after 6 or 7 hours operation at this high loading. Unfortunately, less than a 1 to 1 recirculation ratio could be employed, which probably accounted for the septic action. It was felt that if the physical arrangement of the plant were such that a 3 or 4 to 1 recirculation ratio could have been used, sufficient oxygen would have been present in the primary clarifier to prevent septic action.

The chief objection to the use of trickling filters on carbonaceous industrial wastes is the time required to bring them up to maximum efficiency. It takes anywhere from a few days to a couple of weeks to develop bacterial gel on the filter stone. For canneries operating for a short period each year it may mean that the season is well advanced before the treatment plant has reached maximum efficiency.

Fortunately, canneries and most food processing plants on the West Coast operate during a much greater portion of the year than do those in the Middle West. This not only aids in the operation of trickling filters but also justifies a greater capital expenditure for the plant in order to reduce operating costs.

When it becomes necessary to reestablish the bacterial growth on the filter stone, it can be done by feeding domestic sewage, or similar material, to the filters for a few weeks. Covering the filters in cold climates materially aids the process, but this additional expense is seldom warranted on the Pacific Coast.

Chemical Precipitation

Chemical precipitation has been used rather extensively on cannery wastes, particularly for vegetables. Wisconsin has taken the lead in this respect and for their conditions it probably is the best solution of the problem. Their seasons are short and the canneries relatively small, both factors which favor high operating costs and low capital costs.

It should be pointed out that chemical treatment does not remove the dissolved solids. This is a distinct disadvantage for wastes high in sugar.

Chemical precipitation may be more expensive than anticipated. For instance, the National Canners Association bulletins show chemical dosages of 9 lb. of hydrated lime and 8 lb. of ferrous sulfate per 1,000 gal. of corn cannery wastes. These figures were probably worked out on wastes having a 5-day B.O.D. of about 2,000 p.p.m. However, at Plainview, Minn., it was found necessary to use 18 lb. of hydrated lime and 22 lb. of ferrous sulfate per 1,000 gal. of waste having a B.O.D. of about 8,000 p.p.m. Based on lime cost at $12 and ferrous sulfate at $35 per ton, the chemical cost was about 50 cents per 1,000 gal. of waste treated.

Lagooning

Lagooning of industrial wastes has been and is still being practiced to a considerable extent. It is satisfactory where the proper location is available

to prevent an odor nuisance or the pollution of underground waters. The addition of sodium nitrate to the raw waste in sufficient quantity to satisfy the initial B.O.D. aids in reducing odors.

Minnesota has favored the lagooning of cannery wastes where suitable sites are available. Due to the short canning season in that state, the lagoons have an opportunity to recover during the winter and spring months. It has been found that freezing greatly aids the process. The formation of ice causes the solids to be rejected and forced toward the bottom of the ponds where digestion eventually takes place.

Predigestion

Predigestion of industrial wastes was discussed by the author in the 1945 issue of California Sewage Works Journal (4). This method of treating high strength wastes is not new, as plants are in operation at Standard Brands, Inc. at Pekin, Ill., Commercial Solvents Corp., Peoria, Ill., and more recently at the U. S. Sugar Corp. at Clewiston, Florida.

Predigestion is applicable to wastes having relatively high B.O.D.'s, probably in excess of 1,000 p.p.m. This is particularly true for wastes high in colloidal and dissolved solids.

Predigestion is the least expensive method of reducing B.O.D. Operating costs are low, particularly if the digestion tanks are heated with waste steam, or if the gas produced in the digestion process is collected and used for heating. Larger installations may actually show a profit if there is provision for utilizing the gas in the manufacturing plant.

The amount of gas produced is a function of the percentage volatile matter of the raw solids and the detention time. Most of the food processing wastes are high in volatile matter, probably exceeding 80 per cent. Even with the short digestion periods generally used in this process, 7 cu. ft. or more of gas can be expected from each pound of solids added.

Wastes are stabilized by predigestion and thereby prevent septic action taking place in the sewers leading from the industrial plant to the city sewage treatment plant. The material which would readily become septic has been reduced by digestion and the pH brought to the alkaline side so that septic action and odors are not likely to develop in the sewers.

Predigestion has the further advantage of converting many of the colloidal solids to settleable solids. In experimental work at the Lakeside Packing Company, Plainview, Minn. (4), it was found that the suspended solids of corn cannery wastes would settle very readily after digestion while little or no clarification took place in the raw wastes. As a result, the B.O.D. reduction shown in the supernatant liquor average 87 per cent compared to 60 to 65 per cent for the mixed sludge.

Predigestion as a method of treatment should be investigated for various types of cannery wastes as well as for those from wineries and other food processing plants.

In order to reduce the size of digestion tanks only the concentrated wastes should be treated. Surveys should be made of each plant so the wastes could be separated, with the more concentrated going to digestion units and the others used for diluting purposes after digestion. At the Lakeside Packing Company, approximately 50 per cent of the flow was cooling water having practically zero B.O.D.

There is some question whether or not fruit canning wastes have sufficient nitrogen present for proper digestion. Before attempting such treatment, an investigation should be made to determine the carbon-nitrogen ratio of the waste. Some investigators state that it should not exceed 10, but there are indications that good digestion can be obtained with ratios of 20, or pos-

sibly even higher. If the nitrogen content is not sufficient, it would then be necessary to add nitrates in some form. Sludge digestion tanks as ordinarily designed do not take full advantage of tank volume for short period digestion. The digesters at the U. S. Sugar Corp. plant at Clewiston, Fla., have mechanisms designed so that the raw waste is distributed over the entire bottom of the tank and passes upward to the outlet located near the top of the tank. This tends to prevent short circuiting and gives maximum contact of the waste with the bacteria.

The holding time required to maintain digestion depends upon the type of material being digested. Probably wastes high in nitrogen digest faster than those having a higher carbon-nitrogen ratio. For corn cannery wastes the digestion time appeared to be somewhere between 5 and 10 days for mesophilic digestion. For certain other wastes the time may be found to be less than 5 days.

To date predigestion has not been practiced on seasonal wastes. The question naturally arises whether the process can be kept active during the period when no wastes are produced. There is a good possibility, however, that the sludge will remain active, particularly if brought up to temperature before new sludge is added.

B.O.D. reductions by predigestion depend upon the detention time and the type of material digested. Experience indicates reductions between 60 and 90 per cent for a holding time of between 4 and 10 days.

Pilot Plant Studies

There is a need for pilot plant work to study the various and most economical means of treating wastes from the various types of industries. It is not a question of lack of knowledge about possible methods of treating carbonaceous wastes, but rather one of finding more economical means of treating certain specific wastes. It is only through the operation of pilot plants that it is possible to determine the type of plant and loadings which will produce satisfactory results at the least cost. Tests of several treatment processes together with various loadings can be carried on simultaneously so that direct comparisons can be made.

In recommending pilot plant studies, care should be taken to make sure the industries understand the reason for the recommendation. Otherwise they may interpret it as meaning the sanitary engineering profession has not found a method of treating their particular waste. This may be true for certain wastes, but generally not for the carbonaceous wastes.

The value of pilot plant work was well demonstrated several years ago on packing house waste treatment at Mason City, Iowa (5). While the pilot plant work cost the Jacob B. Decker & Sons Packing Company about $15,000, many times this amount was saved in the construction cost of the plant developed over what a conventional treatment plant would have cost. Various arrangements of trickling filters and the activated sludge process were studied. At times, 12 or 13 separate plants were being tested. These studies revealed the advantages and limitations of the various treatment methods. The plant developed from this work has now been in operation over 17 years, turning out a satisfactory effluent with a loading greater than 50 per cent over the design capacity.

The cost of pilot plant work should be shared by all industries engaged in the same type of manufacturing. If this is handled on a cooperative basis, the cost to any one company is negligible and the work can be carried on much more efficiently than if the cost must be borne by an individual company. An example of such cooperation is shown by the pulp and paper industry in the formation of the National Council for Steam Improvement. This

has been described by Gehm (6). Many other industries would do well to follow this lead.

Conclusions

1. Industrial wastes now polluting streams and waterways have a population equivalent about twice that of domestic sewage not yet provided with treatment.

2. Carbonaceous wastes can be treated by conventional sewage treatment methods, but these methods may be costly.

3. The minimum treatment given food-processing wastes should be screening, with the size of openings determined by the type of waste and the subsequent treatment, or disposal.

4. Vacuum flotation removes a high percentage of suspended solids from fruit wastes with short detention times.

5. Trickling filters are more satisfactory than the activated sludge process for the treatment of carbohydrate wastes.

6. Predigestion of high B.O.D. wastes offers an economical method of pretreatment.

7. There is need for more pilot plant studies to reduce costs of industrial waste treatment.

References

1. "A Report on Procedure for the Handling of Industrial Wastes." *Calif. Sewage Works Jour.* (1945).
2. "Plain Thinking about Industrial Wastes." Editorial, *Sewage Works Engr.*, **XVI**, 10, 487 (Oct., 1945).
3. Hyde, Charles Gilman, Gray, Harold F., and Rawn, A. M., Report on "The Collection, Treatment and Disposal of Sewage and Industrial Wastes of the East Bay Cities, California," June 30, 1941.
4. Nelson, Frederick G., "Predigestion of Industrial Wastes." *Calif. Sewage Works Jour.*, **XVII** (1945).
5. Levine, Max, Nelson, F. G., and Dye, Elmer, "Experiments on Purification of Packing-House Wastes at Mason City, Iowa." Bull. 130, Iowa Engineering Experiment Station, Iowa State College, Ames, Iowa (Feb., 1937).
6. Gehm, Harry W., "Trends in Handling Pulp and Paper Waste." *Sewage Works Engr.*, **XVI**, 10 (Oct., 1945).

STREAM POLLUTION SYMPOSIUM

The stream pollution symposium scheduled for Cincinnati will be of considerable interest to readers in the entire Ohio River Valley. During the summer, the "Ohio River Valley Water Sanitation Compact" will become effective, committing the eight states comprising the river system to a program of stream pollution abatement. The purpose of the Cincinnati symposium is to provide a medium for disseminating the technical information essential to the solution of stream sanitation problems.

Date: October 16, 1948.

Place: Engineering Society Headquarters Building.

Title: "Symposium on Water and Waste Treatment."

Stream Pollution

OXYGEN PRODUCTION IN WATER BY PHOTOSYNTHESIS

By W. E. Abbott

Chemist, Sewage Disposal Department, Nottingham Corporation, England

Settled sewage flowing slowly over certain areas of the Nottingham sewage farm is visibly transformed in summer into a suspension of algae in a fairly clear liquid. Such an effluent is bad when examined by methods which measure organic matter, which is not surprising since chlorophyll converts carbon dioxide into organic matter. The usual tests do not distinguish between the original organic matter and the product of photosynthesis. The problem of evaluating somewhat similar effluents has been discussed by Caldwell (1).

Anticipating that a sample containing chlorophyll would show differences in dissolved oxygen content after incubation at the same temperature in daylight and in the dark, the author was nevertheless struck by the magnitude of this difference when experiments were made. This led to an examination of the significance of incubation in the dark during the B.O.D. test.

Experimental

Everything depends on the method of illumination. Incubation at a north window was selected as a simple procedure. Duplicate bottles were wrapped in two layers of brown paper and incubated alongside the others. The room was maintained at about 17° C. by thermostatically controlled electric radiators. Table I summarizes the results with settled sewage. The effect of light was not overwhelming up to 3 days. Photosynthesis must await the development and multiplication of the chance germs of chlorophyll-bearing organisms present.

Table II gives the results with irrigation effluents colored a marked green. In all cases there was a large net production of oxygen in less than 3 days on exposure to light. The facts are consistent with an accelerating rate of oxygen production in the bottles exposed to light. The differences between corresponding bottles incubated in the dark and in light were enormous.

Samples of the kind of effluent under discussion were also incubated in a south window in sunlight. Table III shows that oxygen production was intensified in the stronger light. In all cases dilution was made more or less as for the ordinary B.O.D. test. The visible green of all the bottles always

TABLE I.—Dissolved Oxygen Absorption of Settled Sewage at 17° C.

Sample No.	Incubation (days)	Dilution Ratio	Dissolved Oxygen Absorbed (p.p.m.)	
			At North Window	In Dark
1	3	1:29	108	175
	5	—	78	205
2	3	1:24	160	170
	5	—	215	219
	7	—	171	—
3	3	1:29	202	212
	5	—	263	275
	7	—	289	—

TABLE II.—Change in Dissolved Oxygen Content at 17° C. of Effluents Containing Chlorophyll

Sample	Dilution	Time	Period of Incubation		Dissolved Oxygen Content (p.p.m.)	
			Days	Hours	At North Window	In Dark
1	1:4	3 P.M.	nil	—	7.73	7.73
		9 A.M.	2	18	30.71	0.06
		1 P.M.	2	22	44.70	0.00
2	1:4	3 P.M.	nil	—	8.42	8.42
		3 P.M.	1	0	17.10	5.20
		9 A.M.	1	18	17.50	4.49
3	1:7	2 P.M.	nil	nil	8.49	8.49
		9 A.M.	2	19	18.30	1.51
		4 P.M.	3	2	24.30	0.65
4	1:4	4 P.M.	nil	—	9.64	9.64
		3 P.M.	1	23	16.22	6.66
		9 A.M.	2	17	15.24	—
5	1:9	3 P.M.	nil	—	10.03	9.87
		2 P.M.	1	23	13.52	8.09
		9 A.M.	2	18	13.43	7.42
		2 P.M.	4	23	28.56	6.24

increased sooner or later on exposure to light. The dissolved oxygen figures are consistent with an acceleration in oxygen production.

Care must be taken that seeding with algae does not arise from the diluting water or glassware. The dilution water used in these studies was an unchlorinated deep well water.

It is always important to learn to what extent dissolved oxygen changes are due to nitrification. Duplicate bottles of Sample 5 in Table II were therefore analyzed before and after incubation. The figures at the start, after incubation for 5 days in the light, and for 5 days in the dark were 3.1, 1.5, and 2.9 p.p.m. of ammonical nitrogen and 0.56, 0.47, and 0.51 p.p.m. for nitrate nitrogen, respectively. Nitrite nitrogen was practically nil in every case. Thus, the only significant change was the reduction of ammoniacal nitrogen by half in the case of the bottle exposed to light for 5 days. It is probable that some of this loss is represented by the conversion of nitrogen to more complex forms by photosynthesis. Nitrification was clearly not a factor in either case.

TABLE III.—Production of Dissolved Oxygen in Strong Light at 18° C. by Effluents Containing Chlorophyll

Sample	Dilution	Time	Period of Incubation (hours)	Dissolved Oxygen Content at South Window (p.p.m.)
1	1:19	1 P.M.	0	10.84
	—	3 P.M.	2	13.94
2	1:4	10 A.M.	0	9.20
	—	1 P.M.	3	22.00
	1:19	10 A.M.	0	9.63
	—	1 P.M.	3	13.20

Photosynthetic activity in the class of waters examined is not much affected by the degree of dilution.

The above tests were made on suitably diluted samples. Oxygen change was also studied in mixtures of these liquids without dilution. Mixtures of

TABLE IV.—Dissolved Oxygen Content in Mixtures of Settled Sewage and Effluents Containing Chlorophyll on Exposure to a North Light

Time	Date	Dissolved Oxygen Content (p.p.m.)
(A) One volume of settled sewage to one volume of effluent		
4 P.M.	Oct. 20	7.88
4 P.M.	Oct. 24	0.00
4 P.M.	Oct. 27	11.62
9 A.M.	Oct. 28	4.97
4 P.M.	Oct. 28	15.95
9 A.M.	Oct. 29	7.16
(B) One volume of settled sewage to two volumes of effluent		
3 P.M.	Oct. 13	4.10
4 P.M.	Oct. 14	0.00
4 P.M.	Oct. 16	0.00
4 P.M.	Oct. 17	0.45
9 A.M.	Oct. 20	8.39
4 P.M.	Oct. 20	35.90
9 A.M.	Oct. 21	28.30

settled sewage and green effluents were placed in dissolved oxygen bottles in a north light at a temperature of about 17° C. Equal volumes required about a week to produce oxygen in measurable excess throughout the day. Table IV gives two samples. In A, the sewage is Sample 3 in Table I and the effluent is Sample 4 in Table II. The usual diurnal variation in oxygen content is marked. By the time oxygen can exist throughout the day the filtered samples show that much clarification has in fact taken place. Filtrates from all but the densest filter papers had a greenish tint.

Nature of the Photosynthetic Organisms

No serious attempt was made to identify the organisms causing the changes recorded in this paper. All that need be known is that they possess the essential property of readily developing in a sewage heavily charged with trade wastes.

Discussion

Two simple means of relating the degree of insolation in some measure to the prevailing climatic conditions suggested themselves. One was to immerse the bottles in the river. The other, which proved more convenient, was to incubate at a north window in a room maintained at a convenient temperature. The light entering the bottle increases and decreases, albeit in an indirect way, with the intensity of the light entering a neighboring natural body of water. Forty-eight hours is suggested as the period of incubation since even a raw sewage may evolve substantial oxygen by photosynthesis in 5 days under these conditions.

The difference in oxygen content between bottles incubated at the same temperature in the dark and exposed to light can be taken as an index of the photosynthetic capabilities of the sample. If the degree of illumination were standardized, this index would give a rational estimate of the photosynthetic organisms in a fraction of the time required for the counting and identifying techniques which are so difficult to interpret.

As sewage changes by natural self-purification in light, the difference between the dissolved oxygen after incubation in the dark and in light tends to increase, and the absorption in the dark tends to decrease. Let it be assumed that a sample is suitably diluted and incubated at the same temperature in the dark and in light. Then, if O_0, O_1 and O_d are the dissolved oxygen contents of the water at the start and after incubation in the light and dark, respectively, the ratio $\frac{O_1 - O_d}{O_0 - O_d}$ is low in the case of sewage and increases as the sewage is transformed. In the green effluents examined this ratio was about 3. It may be possible to say that

effluents yielding above a certain value for this ratio would do little harm to many rivers. As this is a ratio, the absolute magnitude of the figures may not be important, and incubation might possibly be carried on in any convenient room.

The B.O.D. test originated in an attempt to measure the spontaneous changes in dissolved oxygen that would occur in a river. The rate of these changes varies with the temperature and other conditions prevailing, and the test has been standardized. In so far, however, as the conditions under which the test is carried out differ from conditions in the stream, by so much does it tend primarily to become just another means of estimating the organic matter in the sample. Incubation in the dark is the invariable custom. This certainly does not measure the effect on discharge when the sample is charged with organisms capable of producing oxygen unless, indeed, light is excluded by silt or color or unless the organisms are not viable on discharge. The results of incubation in the dark are no guide whatsoever when applied to a sample from a natural water in which photosynthesis is actually occurring.

In Great Britain, 65° F. or 18.3° C. was chosen for the incubation temperature as the highest temperature normally encountered in a river. But, if one value must be selected for all occasions, a good case can be made for the annual average temperature. Incubation in the body of water in question represents the closest approach to reality. As the author has pointed out recently (2), the B.O.D. principle must be used with understanding, and no single rigidly standarized procedure can be designed for all circumstances.

There is no reason to doubt that the oxygen produced by photosynthesis in an undiluted sewage is usefully employed in oxidation. It is difficult to believe that this oxygen does not result in the production of carbon dioxide, thereby providing basic material for the photosynthetic agents. In fact, so far as can be ascertained in the laboratory, everything points to a form of symbiosis between the photosynthetic and saphrophytic agents.

It has been possible to consider photosynthesis as simply a transformation of carbon dioxide to oxygen. So far there has been no reason to suspect any of the less usual phenomena reported in a recent publication (3).

Summary

Finding photosynthesis an important item in the complex changes occurring in sewage irrigation, an attempt has been made to devise a simple means of measuring the biochemical production of oxygen. It is shown that by incubation for 48 hours at the same temperature in the dark and exposed to the light from a north window it is possible to estimate either the degree to which transformations have been influenced by photosynthesis or by the oxygen-producing capabilities of a sample.

Acknowledgment

This paper has results from the author's participation in a study of sewage irrigation initiated by Mr. A. R. Stone, manager, Sewage Disposal Department, Nottingham Corporation.

References

1. Caldwell, D. H., THIS JOURNAL, **18**, 3, 433 (1946).
2. W. E. Abbott, *J. Soc. Chem. Ind.*, **65**, 87 (1946).
3. C. S. French, Annual Review of Biochemistry, Photosynthesis, **15**, 397 (1946).

THE OPERATOR'S CORNER

CONDUCTED BY S. C. MARTIN

HOST OR HERMIT

Of all the occupational drawbacks that beset sewage works operation as a vocation, none is more common nor more distressing than that of isolation. The average operator works at a plant located at the edge of town or at an out-of-the-way spot along the local stream or river. He labors with few, if any, coworkers. His fellow townsfolk understand little about his work, except in a confused and misinformed sort of way, and almost never visit him. As a result many operators feel more than a little removed from the life and activity of their communities.

This feeling of isolation or separation from community life is not a good condition. At best, it robs the operator of interest and enthusiasm for his work and takes away the satisfaction that should be his for doing a job which is vital to community life. At worst, it fathers an indifferent or even embittered attitude and provides the excuse for self-pity, or slipshod work, or a resigned belief in the unimportance of the job.

Frequent visits by townsfolk can break this feeling of isolation. They bring the community interest to the plant and carry back to the community what they see and hear and feel.

Most plant operators like to have visitors and wish there were more of them to spice the day's work with interest and incentive. Without the occasional breaks in routine which visitors bring, a sewage works job can become a lonely endeavor. More than one plant operator has wistfully said to the writer, "You're the only one who's been down here to see me in weeks." When a man is interested in his job he longs for the opportunity to talk to others about it and to show them what he's done.

Every sewage works man needs the stimulus which visitors always provide. As an occupational pick-up, an intelligent, interested visitor has no equal. Somehow, visitors touch the motivating forces of pride, reputation, and self-esteem in all sewage works men and thus stimulate efforts to improve plant operation. The well-visited plant invariably is a clean, neat, better maintained and more efficiently operated plant.

Few operators, however, will be blessed with visitors if they just sit back and wait for their townsmen to come. If left to his own devices, the average citizen would probably never feel compelled to visit the municipal sewage works. Many operators, however, have overcome this inertia by relating the taxpayer's personal interest to the sewage plant in concrete and practical ways. Where this has been done, the feeling of isolation and separation from community affairs has been dissolved and sewage works personnel have acquired the feeling of being a vital and important part of community life.

This page of THE CORNER in subsequent issues will relate practical methods which operators have developed to stimulate plant visitation and will discuss the advantages which may be anticipated from such programs.

S. C. M.

A NOVEL ARRANGEMENT FOR AVOIDING ELECTRIC MOTOR OVERLOADING

By Ralph A. Hoot

Superintendent, Fort Wayne, Ind., Sewage Treatment Works

One of the most perplexing and tantalizing problems in the early days of operation of the Fort Wayne sewage treatment works was the constant overloading of the screenings grinder motors during grinding operations. As a result the motors frequently had to be removed from service and rewound.

The grinder motors were of 25-hp., 30-amp. size and were protected by overload heaters. Due to the fact that the motors required 300 amp. for starting, the overloads had to be set so as not to "kick out" during starting. This apparently gave insufficient protection during grinding.

Screenings are hand fed into the grinders by plant personnel. In spite of repeated instructions and close supervision, it seemed impossible to keep the screenings feedage rate down to the load limit of the grinder motors. The operators could not be blamed too much since there was no way for them to know when the feedage rate was at or above the 30-amp. load limit.

Actual tests made with recording ammeters indicated that during the grinding period the normal demand of the motors was 40 to 50 amperes. This continued slight overload, in contrast to the 5-sec., 300-amp. starting overload, proved to be more than the motors could handle.

No help was obtained by appealing to the motor manufacturer and the grinding company. Both replied: "Keep the feedage down so that the grinder is not overloaded."

Our plant electrician, James Patch, finally worked out the solution for the problem. He simply inserted an electromagnet on one of the three phases of the 440-volt motor line, and, along with this, installed a 110-volt mercoid switch. These were adjusted so that when the amperage to the motor exceeded the motor rating the magnet would close the switch and a warning light would come on. The wiring diagram for the installation is shown in Figure 1.

Now during grinding operations the operators know when the grinder be-

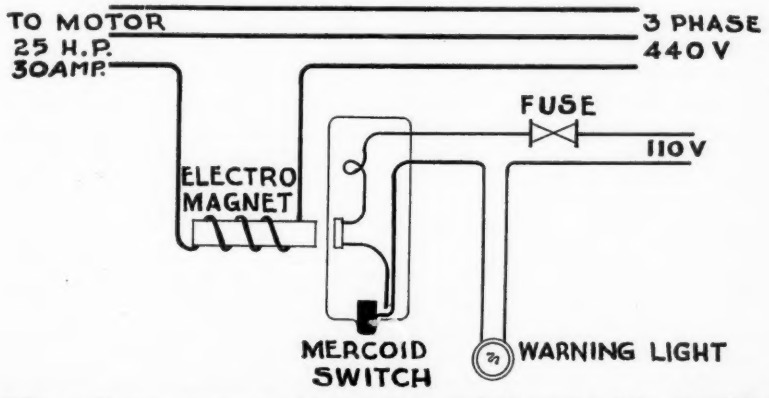

FIGURE 1.—Wiring diagram for grinder motor overload warning light, Fort Wayne, Ind., sewage treatment works.

comes overloaded and can regulate the grinding load accordingly. The warning light is mounted immediately in front of where the men stand, and as long as it stays off they know the grinder load is under the 30-amp. rating of the motor.

The warning light hookup is both accurate and dependable, as has been demonstrated by recording ammeter tests. Further proof of the effectiveness of this device is the fact that since its installation no grinder motors have burned out.

SLUDGE DIGESTION AND METHANE PRODUCTION *

By J. Donald Walker

President, Walker Process Equipment, Inc., Aurora, Illinois

Trouble-free digestion of sewage sludge is a relatively modern development. The day is not too far removed when the digestion of sludge in separate tanks was considered experimental, and the so-called "tried and true" method was the Imhoff tank. When one of the first installations of heated separate sludge digestion was made in Wisconsin a few years ago, a new era in sludge digestion was established. This type of separate digester set the pace for subsequent digestion tank design in this country. It inaugurated an era of better digestion control and the collection and utilization of gas for heat and power.

Development of Separate Sludge Digestion

At first, these separate sludge digestion installations were extremely controversial. Some operated well whereas others gave a great deal of trouble by foaming or by developing heavy scum and grease layers that could not be removed. Also, the necessity of cleaning coils and unstopping gas lines, repairing internal equipment, etc., caused considerable operation nuisance.

Rapid strides have been made in the minimizing of troubles experienced in the anaerobic digestion of sludge until today, except for peculiar industrial problems, continuous, reliable performance can be expected from separate sludge digesters.

One big advancement in the operation of digesters is the increased production of methane to be used as a source of power. For years water treatment plants have been enjoying an enviable position in the Public Works Department because they produced a product which the people wanted and for which they were willing to pay. On the other hand, sewage treatment has been the "unwanted child" of all communities and any cost of operation was always spent begrudgingly.

The utilization of the methane gas produced in sludge digesters today opens the way for the sewage plants to defray a goodly portion of their operation costs. This offers a means of making the consideration of sewage treatment by any community much more popular than it could ever be without this valuable byproduct.

Basic Principles of Starting Normal Digestion

When a digester is first placed in operation or when a serious operating upset has resulted in loss of the digestive process a strong nucleus of methane seeding bacteria will not be present. It will be necessary to establish within the digester the normal biological balance which causes liquification of com-

* Presented at the Annual Meeting of the Iowa Sewage Works Association; Cedar Rapids, Iowa; Oct. 9–11, 1947.

plex organic compounds and the subsequent production of methane by methane bacteria.

The starting or commencing of the entire digestive process will be briefly reviewed.

This establishing of normal digestion has been divided into three phases as follows: (1) the acid production or accumulating stage, (2) the slow acid digestion and regression stage, and (3) the alkaline or methane digestion phase.

At first, the bacteria contained in the raw sewage sludge itself act almost at once upon the concentrated sludge under anaerobic conditions in the digester to produce a condition of intense acid fermentation which probably lasts for about 2 weeks at temperatures of 60° to 80° F. During the acid stage there is relatively little decrease in the volume of sludge and little improvement in the drainability. The pH probably goes down to 5 or 6, a foamy viscous scum appears and hydrogen sulfide odors are given off.

During the second stage, which normally lasts for about 3 months, slow acid digestion takes place. The gas production falls off but the putrefactive odors still remain or get worse, and the pH slowly rises to around 6.8.

At the end of the second stage and after the pH has risen above 6.8 there follows a period which may be called "normal digestion," in which little or no putrefaction odors are given off, the sludge acquires a dark color, takes on a tarry odor, and methane production commences. During this third, or methane, state of digestion, the methane bacteria more-or-less take control of the process and this phase continues until most all of the organic matter is broken down. This desirable third phase can be caused to continue indefinitely in normal digesters if procedures are followed which will be discussed subsequently.

Principles of Methane Production

Sludge digestion is practiced not only for the reduction and liquification of organic matter so as to make possible its disposal without nuisance and in much less volume, but also for the production of methane which is a useful byproduct. Under ordinary circumstances the best conditions for the production of methane are those that satisfy the other reasons for digestion. Accordingly, it may be well to look into the basic principles of methane production and consider the factors which have the greatest effect on the continuous, successful production of methane in the average plant.

The essential physiological characters of the four principle methane-producing bacteria have been very thoroughly described by H. A. Barker of the University of California in several publications published both here and abroad (1), and also in a series of papers by the New Jersey Experiment Station (2) (3) (4). The following paragraphs will briefly summarize the characteristics of these methane producing bacteria, which are absolutely essential to the production of methane in digesters, and will attempt to relate these characteristics to practical plant operation.

In 1936 Professor H. A. Barker made the following statement: "There is probably no important group of bacteria so poorly known as that group which is made up of methane-producing organisms.

"Although the formation of methane is a phenomenon of common and wide spread occurrence in nature and is of increasing importance in sewage purification and disposal of waste products with the simultaneous production of fuel, the existing knowledge of the causative agents of this fermentation is still very slight. This is evident from the fact that not a single representative of the group is listed in the standard works on bacterial taxonomy

(Bergey, 1934; Lehmann and Neumann, 1927)."

In reviewing the characteristics and requirements of methane-producing bacteria it should be realized that in the past biochemists and bacteriologists alike have been in the dark as to the activities of these organisms because they cannot be studied by ordinary, standard bacteriological methods. It was only 10 years ago that the methane bacteria were classified into their four groups, or types, and it was only about 6 years ago that the first pure culture of methane bacteria were isolated and studied in pure culture, and their characteristics and actions definitely determined.

A brief review of the action of methane bacteria in the process of anaerobic sludge digestion reveals the following. To produce methane, methane bacteria and their enzymes must be available to break down the various complex organic compounds into methane gas. This methane fermentation has been reduced to a simple formula which is very similar to the sulfate reduction formula, which is:

$$4H_2A + H_2SO_4 \rightarrow 4A + SH_2 + 4H_20$$

In this well-know formula the hydrogen donor is activated by the sulfate which acts as the hydrogen acceptor and is reduced to hydrogen sulfide.

In methane fermentation carbon dioxide is the hydrogen receiver and is reduced to methane. This analogous equation is expressed by the general equation:

$$4H_2A + H_2CO_3 \rightarrow 4A + CH_4 + 3H_2O$$

where four parts of organic are activated by bacteria to donate H_2, which reduces CO_2 to yield one part of methane gas, three parts of water, and four parts of the oxidation product of the organic. In this case the H_2A represents any compound, organic or inorganic, which can be activated by methane bacteria to act as a hydrogen donater for the reduction of carbon dioxide. The carbon dioxide acts as the hydrogen acceptor. The end products of the biochemical reaction are oxidation products of the organic compound—methane and water.

The methane bacteria which activate the hydrogen donor can be classed into four general classifications; namely, a sarcina, a coccus, and two kinds of rod-shaped organisms. It is not to be implied that these are the only types of methane-producing bacteria because it is highly probable that other species will eventually be recognized. However, the four types which have been enumerated are the most common and probably the most important.

The principal methane bacteria studied in these four groups were found to be strict anaerobes with extreme sensitivity toward the presence of oxygen, and much greater sensitivity than most other anaerobic organisms. These bacteria will ferment a great variety of organic matter with the production of methane only. They lack ability to produce even low-heat resistant end spores. These organisms require carbon dioxide for metabolism and have a very low rate of development; that is, a slow growth. Their nitrogen requirements are satisfied with ammonia nitrogen since they require only inorganic nitrogen sources. They require a hydrogen donor and carbon dioxide as a hydrogen acceptor in order to produce methane.

Temperature is very important and their temperature range is between the limits of 68° and 118° F., with an optimum range of 80° to 95° F. The greatest development and activity occurs near the latter figure. This will surprise most people.

Hydrogen-ion concentration is also highly important. The bacteria live in a range between pH 6.5 and 8.1, with an optimum pH between the limits of 6.9 and 7.2.

Practical Application to Plant Operation

Studies of sewage sludge undergoing anaerobic fermentation have been made to determine where the greatest numbers of methane bacteria are found. These studies indicate that much greater numbers of methane bacteria are found in the sludge beneath the supernatant liquor than in the supernatant itself (2). This is somewhat contrary to work published in 1929 in which it was claimed that the seeding value of supernatant liquor was greater because active organisms in greater numbers were found in the supernatant liquor than in the digested sludge (5). This discrepancy might be explained inasmuch as in the 1939 work methane-producing bacteria were being studied, whereas in the earlier work evidently other than methane types of bacteria were studied.

Since it was found from these studies that more than 10 times as many methane bacteria were found in the bottom sludge as in the supernatant liquor, it should be desirable to provide mixing of the digested sludge with the new sludge pumped to the digester in order that it be properly buffered and inoculated with methane bacteria.

Methane bacteria are obligate anaerobes and, accordingly, it is highly desirable to avoid any air entrainment or oxygenation of the sludge. This should be a very easy requirment to meet unless faulty pumps acting under high suction lifts are used, breaking up of grease at the suface or violent hosing is resorted to, or any other source or form of oxygen introduction is practiced.

Circulation

In order to avoid local concentrations of raw sludge which has not been properly buffered and seeded, it seems desirable to provide some form of circulation of the digester contents so that digested sludge can be mixed with the raw sludge being pumped into the digester. The buffering action of the circulating and digesting sludge will keep the pH of the new material well within the optimum range of good methane production, and, of course, the mixing of great numbers of active methane bacteria with the new sludge will cause immediate methane production. If positive circulation or admixing in some form is not practiced, there is danger of intermittent methane production and little or no digestion in the top scum layer. There is even some danger of the entire digester reverting to the acid stage of digestion with the subsequent well-known ill effects. At the very least, lack of circulation facilitates the formation of a heavy top grease layer which may become objectionable.

Natural Mixing

A few years ago it was considered that the natural ebullition of gas within the digester itself acted to cause sufficient stirring of the contents for buffering and seeding action on new sludge. The claim was that small particles of sludge from the lower zones of the digester would be carried upward by the generated gas bubbles and, having reached the top of the digester, would be released to pass downward through the digester as the gas passed off. The danger of depending upon natural gas circulation is that when localized "pockets" of raw unseeded and unbuffered sludge do form, or when the temperature conditions are not proper for the production of methane bacteria, the ebullition of gas falls off. Thus, the whole mixing system goes into a vicious cycle wherein as the gassing diminishes the mixing also reduces. Consequently, methane production stops, and the digester probably will start to become acid.

Example of Positive Mixing

A typical example of the advantage of positive digester mixing and the

admixing of new sludge with recirculating liquor was reported by Gunson of Denver, Colorado (6). At this plant better and more uniform results were obtained by changing the recirculation of sludge so that partially digested sludge from the bottom of the primary digester was mixed with the incoming raw sludge before it entered the tank. This method insured the immediate start of digestion as well as the increased and uniform production of gas, which had not been realized before this method of operation was practiced.

Heating

For best methane production it is probably necessary to control the digester temperature within a relatively narrow range, between the limits of 85° to 95° F. Of course, methane production will occur with the temperature as low as 65° F., but below 82° F. it starts to slow up markedly. Because of the difficulty in heating digesters to the optimum temperature it is customary for a good many plants to run at a temperature much less than is indicated. This condition is caused by the loss of heat through uninsulated walls and the necessity for keeping temperatures in hot water coils low enough (130° F.) to avoid surface caking and consequent insulation of coils.

More and more consideration is being given to the insulation of digesters, and with the great advancement in the past few years in efficient, cheap insulations it is probable that more attention will be given to this point.

There also is a growing tendency toward using outside heat exchangers instead of internal coils so that the exchanger may be serviced easily and without any necessity of entering the digestion tank. Emptying and entering the digestion tank has proved to be an extremely dangerous and often fatal job for many operators. With the use of outside heat exchangers it is possible to operate at higher temperatures because caking on the coils is no longer an operating danger. It also is possible to bring immediately the fresh sludge to the optimum digestion temperature as well as admix with it the necessary buffering and seeding sludge from the digester proper.

pH Control

pH control is very important since methane bacteria only thrive in the pH range from 6.5 to 8.1, with an optimum range from 6.9 to 7.2. Notwithstanding that some plants are reported to operate well at a pH of 6.8, there is no assurance that these plants are operating with maximum methane production, and also, there is always the possibility of missing the actual pH by plus or minus 0.1.

There are two general ways of controlling pH. They consist of (1) recirculation of digested sludge having the proper pH to act as a buffering agent on the fresh sludge, and (2) raising the pH with the use of lime or some other caustic, or lowering the pH with the use of carbon dioxide. Quite often when the digester is being placed in operation or when for some reason acid digestion starts to take place, it is necessary to add lime to raise the pH so that good liquification and methane production may start. In plants not equipped for recirculation it is difficult to obtain good results by adding lime, because the introduction of lime, by whatever means, is apt to result in a high localized concentration. Such a concentration will act partially as a detriment by sterilizing adjacent portions while it slowly raises the pH of the whole mass as the causticity is gradually diffused.

Where industrial wastes carrying a high causticity are encountered it is relatively simple to adjust the pH by dissolving stack gases (CO_2) into the recirculating liquor so that the optimum pH can be realized.

Grease Accumulations

Although grease cannot be directly reduced by methane bacteria, its pres-

ence does not exert a deleterious effect on the production of methane. Methane organisms cannot use complex organic materials such as fats, celluloses, and proteins directly. These materials must be hydrolized by other organisms into simpler compounds, such as acetate, butyrate, and ethyl alcohol ferments, before the methane organisms can use them.

In cold climates the foamy grease floating as the top layer in a digester acts somewhat as an insulator and conserves a great deal of heat in the digester. A very small amount of commercial insulation would act as a far more efficient insulator, but such insulation is not generally included in digester construction at the present time.

It has been observed that at some institutions, in hospitals, and particularly in military camps, that the amount and freshness of grease received at the sewage plant gives considerable trouble. A good deal of this trouble is probably occasioned because many of these digesters were built without heating facilities, since it was considered that the climate was sufficiently warm to excite bacterial action. No consideration was given to the fact that, although the yearly temperature is relatively high, the winter temperature is below that required for the efficient liquification of grease. Several instances have been observed where the entire top of a covered digester was lifted off and broken, and reinforced beams as deep as 3 ft. were broken in two like twigs by the multiplied hydraulic pressure developed by pumping sludge when grease had completely clogged all overflow and gas pressure reliefs. In several such cases it was necessary to break off the covers and dig the grease out of these digesters, as often the grease layer extended from the top completely to the bottom of the tank. It is felt that more attention to recirculation and heat control for these digesters would have avoided this condition.

General Conditions

In general, the conditions which are optimum for the liquification and the break down or stabilization of organic matter are very close to the conditions which affect the production of methane. However, conditions in digesters which result in reasonably good liquification and stabilization of organic matter and which produce a sludge that is easily dried on the sand drying beds do not always effect efficient methane production. Accordingly, a good many operators looking for more efficient methane production will find it necessary to carry higher temperatures, to watch the pH more closely, and to practice recirculation. Recirculation will give better buffering and seeding of the freshly added sludge and will prevent localized concentrations of unseeded and unbuffered raw sludge.

Liberal design capacities and gas escape areas in digesters seem to be other requirements for satisfactory digester operation and efficient methane production. This is particularly important in the smaller plants where in many cases only a single digestion tank is economically feasible.

In all installations the operator should be provided with outside digester circulation so that the mixing of raw sludge with digested sludge can be controlled for best methane production.

Above all, the operator should be considered, and means and methods provided whereby he will never have to unwater and enter the digester proper. Precautions should also be taken to make plants more fool-proof from explosions.

While larger plants can easily plan on using methane for the operation of engine-driven pumps or gas engine generators, it is not feasible to place such complicated devices in extremely

small plants. However, digester gas can be easily utilized in small plants for heating the digester, and there is always the possibility of operating small, simple, gas engine-driven recirculation pumps, which would improve the operating characteristics of almost any plant. The smaller the plant the more important gas storage becomes if gas is to be used for power, because the generation of gas in smaller plants is more spasmodic than in larger ones. This is due to weather variations (diluted sewage), longer intervals between pumping operations, and less possibility of maintaining the close digester control necessary for uniform and continuous production of methane.

In institutions, hospitals, and military camps it is necessary to give more thought to the scum and grease accumulations in the digester.

Enough information has now been gathered relative to digester operation and, in particular, to methane production so that controlled digester operation is established in modern design. It is safe to look forward to an increase in the use of methane gas as a usable byproduct which will make the sewage plant quasi self-supporting and more popular in the community which has to support it. Such a state would definitely raise the caliber, morale, and paycheck of sewage treatment works personnel.

References

1. Barker, H. A., *Archiv. für Mikrobiologie* (1936).
2. Heukelekian, H., and Heinemann, Barnard, "Studies on Methane-Producing Bacteria. II. Enumeration in Digesting Sewage Solids." THIS JOURNAL, **11**, 3, 436–444 (May, 1939).
3. Heukelekian, H., and Heinemann, Bernard, "Studies on Methane-Producing Bacteria. III. Digestion of Sewage Solids by the Addition of Enriched Cultures of Methane-Producing Organisms." THIS JOURNAL, **11**, 4, 571–586 (1939).
4. Heukelekian, H., and Heinemann, Bernard, "Studies on Methane-Producing Bacteria. IV. Growth of Methane-Producing Organisms in Supernatant Sludge Liquors." THIS JOURNAL, **11**, 6, 965–970 (1939).
5. "Studies on Two-Stage Sludge Digestion." Illinois State Water Survey Bull. No. 29 (1928).
6. Gunson, C. P., "Controlled Heat and Mixing Improve Stage Digestion." *Sewage Works Engineering*, **12**, 1, 20–21 (Jan., 1943).

CORROSION TEST OF SCREEN WIRE AT SEWAGE WORKS

By R. S. YOUNG

Chief Research Chemist, Rhokana Corp., Ltd., Nkana, Northern Rhodesia, South Africa

Wire screens are frequently used at sewage treatment works for excluding flies and other insects from entering the buildings through doors and windows. Occasionally, screen wire may also be used to prevent fly and mosquito breeding in tanks, filters, or sludge beds.

A 2-year test of the corrosion of different screen wire materials under tropical conditions has recently been completed. The results will undoubtedly be interesting to many in the sewage works field.

Several years ago four Imhoff tanks of the Rhokana Corporation, Nkana, Northern Rhodesia, were covered with ordinary galvanized iron window screen. These screens failed rapidly. Painting with an acid-resistant bitumastic paint did not appear to materially delay corrosion.

Following this experience, two prominent American manufacturers of wire screening were contacted and samples of screening suitable for corrosive conditions were requested. The samples received were placed in position over

TABLE I.—Results of Exposure Test of Screen Wire at Rhokana Corporation, Ltd., Nkana, Northern Rhodesia, South Africa

Sample No.	Manufacturer	Type of Screen	Remarks
1	W. S. Tyler Co., Cleveland, Ohio	Stainless steel, 12 mesh	Perfect condition. No loss of weight or sign of corrosion.
2	W. S. Tyler Co., Cleveland, Ohio	Phosphor bronze, 12 mesh	Not satisfactory. Severely corroded.
3	Newark Wire Cloth Co., Newark, N. J.	Stainless steel, 20 mesh	Perfect condition. No loss of weight or sign of corrosion.
4	Newark Wire Cloth Co., Newark, N. J.	Monel metal, 20 mesh	Not satisfactory. Severely corroded.
5	Newark Wire Cloth Co., Newark, N. J.	Everdur, 20 mesh	Not satisfactory. Severely corroded.

the Imhoff tanks in August, 1945, and were removed in August, 1947. The results of the 2 years of continuous exposure to the gases rising from the Imhoff tank and to the atmosphere are presented in Table I.

In view of the results of the test, it is apparent that phosphor bronze, Monel, or Everdur screen wire is not satisfactory for permanent installation under conditions similar to those of the test. Stainless steel wire cloth, however, showed no sign of corrosion in the test period. It must be appreciated that, because of the tropical conditions which existed, the 2-year test period was the equivalent of many years exposure under temperate climatic conditions.

Stainless steel wire screens proved completely satisfactory in a 2-year exposure test over Imhoff tanks in the tropics. Phosphor bronze, Monel, Everdur, and galvanized iron screens painted with acid resistant paint failed under the same conditions.

INTERESTING EXTRACTS FROM OPERATION REPORTS

Rust destroys the same metal that the hammer hardens.
—*KVP*

Attention operators! It will be appreciated if copies of all annual reports of both large and small plants are sent to the Federation office for abstracting in this section of the Journal. Carbon copies of typewritten reports will be promptly returned on request. Please direct annual reports to: Federation of Sewage Works Associations, Room 325, Illinois Bldg., Champaign, Ill.

Report on the Administration, Operation, and Maintenance of the Division of Sewage Disposal, Department of Public Utilities, Cleveland, Ohio, for the Year 1946 *

By J. W. Ellms, *Commissioner*

Cleveland is served by three sewage treatment works, the combined operation cost of which exceeds a million dollars yearly. The Westerly plant provides primary treatment with chlorination of the effluent during the bathing season. Sludge disposal is by digestion, vacuum filtration, and incineration. The Easterly plant provides

* For previous extracts see: This Journal, **12**, 3, 625 (May, 1940); **15**, 1, 99 (Jan., 1943); **18**, 1, 113 (Jan., 1946).

TABLE I.—Total Adjusted Costs for Administration, Operation, and Maintenance of Sewage Treatment Plants, Cleveland, Ohio, for 1946

Item	Easterly Plant	Westerly Plant	Southerly Plant	Total
Sewage flow (m.g.)	33,478.3	10,162.7	13,292.7	56,933.7
Operation and maintenance costs ($)	525,543.90	145,693.60	186,658.61	857,896.11
Administrative costs ($)	87,213.19	26,475.43	34,633.13	148,321.75
Total costs ($)	612,757.09	172,169.03	221,291.74	1,006,217.86
Operation cost per m.g. ($)	15.69	14.33	13.40	15.07
Administration cost per m.g. ($)	—	—	—	2.60
Total cost per m.g. ($)	18.29	16.93	16.00	17.67

complete treatment by activated sludge, with all sludge pumped 13 miles to the Southerly plant. Complete treatment by the use of trickling filters and activated sludge is effected by the Southerly plant. Sludge disposal for the solids collected and for those received by pumping from the Easterly plant is by separate digestion, vacuum filtration, and incineration.

The prorated costs of the Southerly plant allocable to the Easterly plant have been made in the following cost table (Table I). Administrative and other costs are apportioned on the basis of the volume of sewage entering the respective plants.

Report on Operation and Maintenance of the Easterly Sewage Treatment Plant

By Walter E. Gerdel, *Superintendent*

The Easterly sewage treatment plant was under the supervision of J. J. Wirts for the first 11 months of the year. It functioned in a normal manner the entire year, and provided complete treatment for 99.9 per cent of the sewage processed. The average flow treated per day was 91.7 m.g.

One of the major achievements was the low air requirements, which amounted to 0.79 cu. ft. per gal. of sewage. A corresponding decrease in electrical power costs was simultaneously realized.

A full year's experience was also obtained with wasting activated sludge to the Easterly raw sewage, instead of pumping direct to the Southerly plant. This procedure resulted in normal purification results of the Easterly sewage, and at the same time there was produced the most concentrated sludge ever pumped to the Southerly plant.

Comminutors and Detritors

Replacement of the cutting elements in the 54-in. Comminutors amounted to 2,147 reconditioned teeth, 17 combs, and 62 shear bars. This maintenance work was performed entirely in the plant machine shop and resulted in considerable savings being accomplished. At the end of the year, all four 54-in. Comminutors were deeply grooved in the upper drum sections, and solids of considerable size were passing through.

Bar Screens and Grit Chambers

The bar screens and grit chambers operated a total of 4,043 chamber hours.

This equipment, as in the past, was used chiefly during storm flow periods, and treated about one-eighth of the total raw sewage flow. A total of 35,600 cu. ft. of grit was removed.

The practice of operating five or six grit chambers one day a week in addition to two 54-in. Comminutors was continued. It has been found that the lowering of the sewage level in the main interceptors induces large amounts of grit to flow into the plant, and helps to reduce the amount of grit that would normally be received during storm flows.

The installation of solid Transite stop boards was completed in all grit chambers in February.

Southerly Pumps and Force Main

A total of 208 m.g. of sludge, containing 3.5 per cent of dry solids, was pumped 13 miles through the 12-in. force main to the Southerly plant for final disposal. Based on the analysis of samples taken at the Southerly end of the force main, 60,873 million lb. of dry solids were transported in the sludge. The sludge pumped was the most concentrated ever delivered and compares to 3.3 per cent dry solids achieved both in 1944 and 1945.

Considerable rag-clogging difficulties at the pumps necessitated a great deal of "cleaning out" maintenance work. It is believed that the worn condition of the 54-in. Comminutor drums is the chief cause of this condition. Easily removable handhole plate openings were made on the suction elbows of the pumps, in an effort to reduce the time and labor necessary to relieve the stoppages.

The program of returning the sludge pumps to the manufacturer for repairs and standarization was continued.

Aeration Tanks and Blowers

An average air consumption of 0.79 cu. ft. per gal. of sewage was achieved. The air consumption was the lowest yearly average ever attained for the plant.

The mixed liquor flow from the tanks averaged 1,465 p.p.m. and had an average sludge index of 92. The return activated sludge averaged 5,216 p.p.m. and was returned at 24.6 per

TABLE II.—Summary of 1946 Operating Data, Easterly Plant, Cleveland, Ohio

Item	Average
Raw sewage flow (m.g.d.)	91.7
Settled sewage flow (m.g.d.)	90.8
Screenings removed (cu. ft. per m.g.)	0.20
Grit removed (cu. ft. per m.g.)	4.50
Suspended solids:	
Raw (p.p.m.)	239
Settled (p.p.m.)	155
Per cent removal	35
Final (p.p.m.)	12.1
Per cent removal	95
B.O.D.:	
Raw (p.p.m.)	195
Settled (p.p.m.)	108
Per cent removal	45
Final (p.p.m.)	10.1
Per cent removal	94.8
Oxygen consumed:	
Raw (p.p.m.)	99
Settled (p.p.m.)	69
Final (p.p.m.)	16
Per cent reduction	84
Ammonia (p.p.m.):	
Raw	10.8
Settled	7.9
Final	4.4
Nitrite, effluent (p.p.m.)	0.5
Nitrate, effluent (p.p.m.)	4.7
Sludge pumped to Easterly plant (m.g.)	214.64
Per cent moisture	96.5
Dissolved oxygen (p.p.m.):	
Settled sewage	1.2
Aerator influent (mixed liquor)	1.2
Aerator effluent (mixed liquor)	4.2
Activated sludge:	
Total solids (p.p.m.)	5,216
Volatile solids (per cent)	63.7
Mixed liquor suspended solids (p.p.m.)	1,465
Sludge index	92
Return sludge, per cent	27.1
Air applied, cu. ft. per gal.	0.79
Postchlorination:	
Days applied	90
Application rate (lb. per day)	4,000
Application rate (p.p.m.)	5.3
Residual (p.p.m.)	1.0

cent of the settled sewage flow. The settled sewage entering the aeration tanks contained an average of 1.2 p.p.m. of dissolved oxygen, and the effluent leaving the final clarifiers contained an average of 4.4 p.p.m.

Chlorination

The plant effluent was chlorinated for 90 days during the bathing season. A total of 360,000 lb. of chlorine was used, which amounted to a 5.3 p.p.m. dosage. A residual of 1.0 p.p.m. of chlorine was attained. No chlorine was used for any other purpose during 1946.

Miscellaneous

A gas-fired heater, pilot plant size, was built and operated experimentally for part of the year. A helical coil made out of 6-in. pipe connected together with suitable fittings was exposed to the gas flames and the products of combustion. The coil carried raw sludge which was recirculated. A mechanical pipe cleaner was designed and constructed so that it could be hydraulically forced through the coil to scrape and clean off any scale that might form. It was successfully demonstrated that the pipe cleaner would pass through the coil, although not enough work was done and data collected to indicate the overall practicability of the heater.

Table II is a summary of operation data for 1946.

Report on the Operation and Maintenance of the Westerly Sewage Treatment Plant

By J. O. Barrett, *Asst. Superintendent*

The Westerly sewage treatment plant was operated under the supervision of Walter E. Gerdel, superintendent, for eleven months of the year.

Experiments were conducted attempting to reduce the depth of digester scum layers by the recirculation of supernatant liquor and by recirculation with the addition of ammonium sulfate. Results indicated possibilities but were not conclusive.

An indicating-dial thermometer was installed in the influent channel, providing a more accurate method for determining sewage temperatures.

The presence of pig hair from packing-house wastes caused considerable nuisance at the bar screens during the first three months of the year, 228 cu. ft. being removed from the screens and hauled to the dump.

Sewage Sedimentation

The entire metered flow passed through the Imhoff tanks with a resultant reduction of 32.3 per cent in suspended solids and 19.1 per cent in the 5-day B.O.D. The percentage reduction of suspended solids is slightly less than in 1945 and is the lowest in 6 consecutive years showing a decrease.

Raw sludge, amounting to 26.4 m.g., having a content of 5.65 per cent dry solids, was removed from the Imhoff tanks as fresh solids.

All the Imhoff tanks had been pumped down and the slots washed by August 19th. A total of 317 gas vents was washed, the scum removed being added to the digesters with the raw sludge.

Sewage Chlorination

Because of the proximity of bathing beaches to the Westerly plant, it is desirable to maintain residual chlorine in the sewage effluent at all times during the bathing season. A total of 365,604 lb. of chlorine was used from June 4th to September 18th. A prechlorination application of 230,309 lb., or 63.0 per cent of the total, was added

to the influent for the purpose of reducing odors and preventing gas vent foaming. The addition of 135,295 lb. of chlorine for postchlorination served to maintain a residual for 80.5 per cent of the time in the plant effluent. The average chlorine dosage was 17.1 p.p.m.

Separate Sludge Digestion

The operation of the digesters as primary digestion tanks was continued.

TABLE III.—Summary of 1946 Operating Data, Westerly Plant, Cleveland, Ohio

Item	Average
Raw sewage flow (m.g.d.)	27.8
Grit removed (cu. ft. per m.g.)	3.79
Per cent volatile in grit	29.8
Suspended solids:	
Raw (p.p.m.)	274.0
Imhoff tank effluent (p.p.m.)	186.0
Per cent removal	32.3
B.O.D.:	
Raw (p.p.m.)	274
Imhoff tank effluent (p.p.m.)	222
Per cent removal	19.1
Oxygen consumed:	
Raw (p.p.m.)	185
Imhoff tank effluent (p.p.m.)	168
Dissolved oxygen:	
Raw	2.9
Imhoff tank effluent	3.4
Total bacteria (1,000 per ml.):	
Raw	2,798
Imhoff tank effluent	655
Per cent reduction	71.8
Presumptive B. Coli (1,000 per ml.):	
Raw	215
Imhoff tank effluent	76
Per cent reduction	62.6
Prechlorination:	
Days in operation	104
Average dosage (p.p.m.)	9.74
Postchlorination:	
Days in operation	81
Average dosage (p.p.m.)	7.32
Ave. residual maintained*	2.16
Raw sludge to digesters:	
Number of additions	77
Total solids (lb. per month)	1,053,600
Temperature (° F.)	61
Total solids (per cent)	5.65
Volatile solids (per cent)	67.3
pH	6.4
Alkalinity as $CaCO_3$ (p.p.m.)	970
Digested sludge vacuum filtered:	
Total solids (lb. per month)	432,700
Temperature (° F.)	76
Total solids (per cent)	6.95
Volatile solids (per cent)	52.9
pH	7.8
Alkalinity as $CaCO_3$ (p.p.m.)	2,690
Digester supernatant:	
Total solids (lb. per month)	87,700
Temperature (° F.)	97
Total solids (per cent)	0.915
Volatile solids (per cent)	52.0
pH	7.9
Alkalinity, as $CaCO_3$ (p.p.m.)	2,710
Sludge storage tank supernatant:	
Total solids (lb. per month)	25,000
Total solids (per cent)	0.82
Volatile solids (per cent)	50.1
pH	7.9
Alkalinity, as $CaCO_3$ (p.p.m.)	2,660
Gas production:	
Daily production (cu. ft.)	210,900
Volatile solids to digesters (lb.)	709,400
Cu. ft. gas per lb. volatile solids	9.0
Utilization of digester gas:	
Digester heaters (per cent)	22.7
Bldg. heaters and miscel. (per cent)	14.1
Incinerators (per cent)	23.0
Wasted (per cent)	40.2
Chemical dosage for vacuum filtration (per cent):	
Ferric chloride	2.75
Lime	14.2
Calcium oxide	12.7
Sludge filtration:	
Filter cake:	
Moisture (per cent)	66.0
Volatile solids (per cent)	45.6
Dry solids (tons)	261
Tons per filter hour	0.72
Ave. filter cloth operating life (hours)	255
Filtrate:	
Total solids (p.p.m.)	3,430
Suspended solids (p.p.m.)	309
Alkalinity, as $CaCO_3$ (p.p.m.)	2,480
Sludge filter cake incineration:	
Tons per month incinerated	585
Tons per incinerator hour	1.16
Tons used for soil conditioner	182
Fuel oil used:	
Gal. per ton filter cake	0.827
Gal. per ton dry solids	0.241
Gas used:	
Cu. ft. per ton filter cake	726
Cu. ft. per ton dry solids	2,115

* Does not include data when no residual chlorine was present.

Practically all of the sludge and scum was pumped to the sludge storage tank for storage and concentration. All supernatant liquor was pumped to the influent of the plant.

An average of 9.0 cu. ft. of gas was produced for each pound of volatile solids added to the digesters. Of the gas produced, 59.8 per cent was consumed to heat digesters, operate incinerators and heat the buildings.

Experiments were conducted using recirculation of digester supernatant liquor to reduce the depth of the scum layer. The addition of ammonium sulfate with recirculation was also tried. The results of the experiments conducted would indicate some beneficial results but the experiments were of too short duration to draw definite conclusions.

Considerable trouble was experienced with blocking of the 3-in. rubber hose used to carry the recirculated digester supernatant liquor to the top of the digesters. Permanent piping changes were made in the control chamber of the four new digesters to permit recirculation of the sludge from the 11-ft. supernatant outlet piping by using two sludge pumps. It was necessary to replace one of the heating coil sections in the hot water boiler for the No. 5 digester. All of the coil sections of this boiler, as well as the other three similar ones, are damaged by corrosion to such an extent that it will be necessary to replace the entire units in the near future.

Filtration

Digested sludge and scum containing an average of 6.95 per cent dry solids, of which 52.9 per cent was volatile matter, were chemically conditioned for vacuum filtration.

Filter cake totaling 9,205 tons was produced, of which 76.3 per cent was incinerated. The balance was used as a soil conditioner by the public, city departments, and the Metropolitan Park Board.

The practice of adding digested scum to digested sludge being chemically treated and filtered was continued and proved a satisfactory method of disposing of scum. The methods used to remove scum from the storage tank were necessarily crude. The scum can be removed only when certain levels exist in the tank.

The new synthetic rubber belts which convey filter cake to the incinerators and which were installed in 1943 and 1945, are in excellent condition and show no perceptible deterioration.

Hot water lines were added to the lime slaking equipment to aid in maintaining the temperature in cold weather.

Short tests were conducted using ferric chloride alone with the ordinary cotton filter cloths. Results were unsatisfactory in every respect. A test of monel wire for holding the filter cloths on the drums was conducted. The monel wire was used 22 times and is still in use. Ordinary galvanized steel wire can be used only twice.

Table III is a summary of operation data for 1946.

Operation and Maintenance of the Southerly Sewage Treatment Plant

By G. E. Flower, *Superintendent*

Sewage Flow

The Southerly sewage plant during the year 1946 treated a daily average of 36.4 m.g. A total of 3,992,800 gal. of settled sewage from the Easterly sewage plant was included in the above metered flow. The practice of pumping settled sewage to the concentration tanks from the Easterly sewage plant was discontinued in September.

TABLE IV.—Summary of 1946 Operating Data, Southerly Plant, Cleveland, Ohio

Item	Average
Raw sewage flow (m.g.d.)	36.4
Screenings removed (cu. ft. per m.g.)	0.519
Grit removed (cu. ft. per m.g.)	1.39
Per cent volatile	64.7
Abbreviated aeration unit:	
Flow (m.g.d.)	17.8
Per cent of total flow	48.1
Air used (cu. ft. per gal.)	0.53
Trickling filters:	
Flow (m.g.d.)	29.6
Per cent of total flow	80
Suspended solids (p.p.m.):	
Raw	210
Imhoff tank eff.	106
Dorr tank eff.	40
Trickling filter eff.	96
Final eff.	55
Dissolved oxygen (p.p.m.):	
Raw	4.5
Imhoff tank eff.	2.9
Dorr tank eff.	1.7
Trickling filter eff.	4.8
Final eff.	3.5
River above plant	10.2
River below plant	8.2
B.O.D. (p.p.m.):	
Raw	165
Imhoff tank eff.	82
Dorr tank eff.	34
Trickling filter eff.	74
Final eff.	42
Per cent reduction	74.5
River above plant	7
River below plant	29
Oxygen consumed (p.p.m.):	
Raw	96
Final eff.	43
Nitrogen—raw sewage (p.p.m.):	
Free ammonia	31
Organic nitrogen	22
Nitrogen—final eff. (p.p.m.):	
Free ammonia	23
Organic nitrogen	16
Sulfates in raw sewage (p.p.m.)	213
Imhoff tank sludge:	
Volume (m.g.)	13.0
Per cent to sludge beds	22.5
Per cent to vacuum filters	75.5
Solids (per cent)	7.0
Volatile solids (per cent)	47.6
Digester operation:	
Raw sludge:	
Volume (m.g.)	230.5
Per cent from Easterly plant	90
Per cent from Southerly plant	10
Dry solids (mil. lb.)	66.0
Volatile solids (mil. lb.)	43.3
Digested sludge:	
Volume (m.g.)	39.6
Dry solids (mil. lb.)	20.6
Volatile solids (mil. lb.)	9.9
Total solids (per cent)	6.2
Volatile solids (per cent)	48.5
Supernatant:	
Suspended solids	3,053
Volatile solids (per cent)	53.8
Gas production:	
Volume (1,000 cu. ft. per day)	864.1
Cu. ft. per lb. volatile solids	7.3
Per cent CO_2 in gas	28.6
Gas utilization (per cent):	
Wasted	39.4
Digester heating	29.3
Incinerators	11.2
Gas engines	14.6
Building heat and miscel.	5.6
Vacuum filtration of sludge:	
M.g. filtered	49.7
Mil.lb. dry solids	26.5
Chemicals used (per cent):	
Ferric chloride	5.6
Lime	16.4
Calcium oxide	14.9
Filter cake production:	
Tons	66,788
Per cent solids	28.0
Filter rate (lb. dry solids hours sq. ft.)	3.19
Filter cloth life (hours)	287
Filtrate:	
Suspended solids (p.p.m.)	320
pH	12.1
Alkalinity (p.p.m.)	3,024
Sludge incineration:	
Sludge cake (tons)	66,321
Sludge cake (tons per incinerator hour)	3.55
Ave. B.t.u. per lb. vol. sol.	11,708

Imhoff Tanks

Slight foaming started in February and March, and gradually increased so that nearly all 12 tanks were foaming in April and May. Foaming had ceased by the early part of June, with the exception of tank No. 12, which continued foaming until the latter part of July. From then on for the balance of the year they operated without any foaming.

Abbreviated Aeration Unit

This unit treated 6,395.3 m.g. of Imhoff tank effluent, or 48.1 per cent of the total metered sewage flow. The suspended solids were reduced 62.2 per cent, and the B.O.D. was reduced 58.5 per cent by this unit.

On August 27th through August 30th, both aeration units were shut down to clean influent and effluent channels. Diffuser plates and holders were removed and replaced with drilled pipe headers in the channels.

Gas Engines

No. 1 engine was shut down for overhauling on February 4th and was completed on March 4th. The overhauling consisted of removing carbon, grinding valves, installing new wrist pin bushings, checking bearings, changing oil, and replacing rings as needed. The expanders back of the oil rings were removed with the hope that the oil would have a better passage to return, and have less tendency to form carbon in the grooves. This did not prove satisfactory as oil consumption was increased. The next time the engine is overhauled, it will be advisable to replace the expanders.

Trickling Filters

The trickling filters treated 10,649.2 m.g. of combined Imhoff tank effluent and aeration unit effluent, or approximately 80 per cent of the entire metered sewage flow. Due to the restricted effluent channel, the lower layers of the filtering media were submerged and the filters did not function satisfactorily. There was considerable pooling on the filters, and tests made of the stones at various depths of the six beds showed a clogging of 52 per cent to 76 per cent of the stones. Analyses of the clogging material on a dry basis showed 68.3 per cent volatile matter, 19.3 per cent as Fe_2O_3, and 5.1 per cent ether soluble matter. From January 1st to June 8th, and from October 21st to December 31st, 7,456.7 m.g. of combined Imhoff tank effluent and Dorr tank effluent were treated by the trickling filters, with an average loading of 3,300 lb. of B.O.D. per acre per day. During this period, the B.O.D. was reduced 30 per cent.

From June 8th to October 21st, the trickling filters treated only Imhoff tank effluent, amounting to 3,192.5 m.g., with an average loading of 3,070 lb. of B.O.D. per acre per day. During this period, the B.O.D. was reduced 54 per cent. If this clogging continues to increase, it will probably be necessary to wash the stones in order to continue the use of the filters.

Concentration Tanks

The concentration tanks were used principally as receiving wells for the incoming sludge. During the months of January, June, July and September, a total of 3.99 m.g. were drawn from these tanks as supernatant liquor and treated by the Southerly plant units. The Easterly plant pumped 208.2 m.g. of 3.5 per cent solids, or 60.9 million lb. of dry solids; and the Southerly plant pumped 22.3 m.g. of 3.0 per cent solids, or 5.41 million lb. of dry solids to the concentration tanks. These sludges were then transferred directly to the digesters.

Vacuum Filtration

Difficulties in obtaining lime during the year created the necessity of using ferric chloride only for conditioning of the sludge part of the time. The rate of filtration was decreased and the amount of ferric chloride was increased, which, in addition to the increased cost of chemicals, increased the cost per ton of the solids processed over the previous years.

Average costs of chemicals for the past 5 years are as follows:

	1946	1945	1944	1943	1942
Average cost of $FeCl_3$, per ton	$38.69	$30.80	$30.80	$30.80	$30.72
Average cost of lime, per ton	10.10	9.80	9.79	8.80	9.19
Cost of lime per ton dry solids	1.64	1.45	1.53	1.29	1.33
Cost of $FeCl_3$ per ton dry solids	2.15	1.62	1.77	1.47	1.54

The usual difficulty of incrustation of filter piping, screens and cloths required a regular routine schedule of acid washing and cleaning.

Incineration

Bending or warping of the rabble arms was one of the major troubles on the incinerators. Insulating the rabble arms on hearths No. 5 and No. 6 helped to eliminate the trouble.

A new alloy arm was purchased from a local company and has been entirely satisfactory. The new arm will withstand the high temperatures without being insulated.

Table IV is a summary of operation data for 1946.

THE WORCESTER FILTER PROBLEM

Roy S. Lanphear, formerly chemist at the Worcester, Mass., plant, suggests that there should be some clarification of the abstracter's note appearing on page 910 of the September, 1947, issue in the extract from the Worcester 1945 annual report. The note reads, "Since this report has been released, it has been decided that major renovation of the trickling filters will be required before filter operation can be resumed."

Mr. Lanphear points out that the deleterious effects of the acid wastes on plant operation were first called to the attention of the authorities concerned in August, 1943. No action was taken to correct the condition during the war, however, the first official move being made in October, 1945.

In March, 1946, Mr. Lanphear recommended removal of the surface clogging material, together with 6 to 8 in. of partially clogged stone. Since the sewage flow had returned to normal character, it was further recommended that the filters be operated in such manner and at such rates as would demonstrate if normal biological conditions could be restored. These recommendations were supported by the Commissioner of Public Works, who requested an appropriation of $20,000 for the work, but the renovation program was abandoned in favor of replacement of the clogged filters with 16 new units equipped with rotary distributors.

It has also been recommended recently that the city council adopt an ordinance placing authority with the Commissioner of Public Works to regulate the discharge of industrial wastes to the sewer system.

SEWER CLEANING AT LITTLE ROCK, ARKANSAS

By T. W. Clapham

Manager, Little Rock Sanitary Sewer System, Little Rock, Arkansas

In 1936–37 the City of Little Rock, Arkansas issued $1,500,000 in bonds and with the proceeds built an intercepting sewer that practically surrounded the city. Old septic tanks maintained by various sewer improvement districts were abandoned, and an effort was made to coordinate the existing sewers so that the new intercepter would carry about 70 per cent of the sewage. The remaining 30 per cent is dumped directly into the Arkansas River, which forms the north boundary of the city. The intercepter starts as a 12″ line up in the hills of the western end of the city and some 62,272 feet later reaches the lift station on the river bank about a mile east of town.

Since this intercepter had shown evidence of becoming overloaded through infiltration during extremely wet periods, and since there was no practical remedy for the general infiltration, it was decided to try to increase the velocity and capacity of this line by endeavoring to clean it in its entirety. Inspection jaunts thru several portions of the larger sections showed that there was a deposit of sand or fine silt in the invert of the pipe. This deposit ranged from 2 in. through 12 in. in depth. It was believed that if the silt was removed the capacity would be increased since the sewer would have a circular section and not one with the chord of a circle for a bottom.

Use of Sewer Scooter

Starting with the 12-in. line in the upper reaches of the intercepter, a sewer "scooter" was used for the cleaning. Placing this tool in the upper manhole, water pressure was built up behind the scooter, with a fire hose used to supplement the normal flow of sewage. A 500-ft. length of ⅜-in. steel tiller rope was used as a tail rope to control the scooter and to flush it when required. It was discovered that tiller rope works much better than fiber rope because it does not float and will not move forward in a steeply pitched sewer unless the scooter itself moves forward.

The debris in each sewer section was trapped in the lower manhole and removed by buckets. Since the scooter has interchangeable heads, it may be used, within limits, for various size sewers. In Little Rock, equipment is available to "scoot" pipe ranging in size from 8 inch through 30 inch. In the larger pipe, however, it is not necessary to supplement the regular sewage flow with hydrant water, as the normal flow builds up pressure quickly enough.

Believing that with 36-in. diameter pipe a scooter would be too hard to flush, it was decided that a hoe would prove more suitable for the balance of the intercepter. This piece of equipment was built by sewer system employees, and was designed so that it would accommodate heads for sewers from 36 in. through 60 in. in diameter.

Sewer Hoe Developed

For the benefit of those who have not used a sewer hoe, it may be said that the writer's experience has proved this to be a most practical and economical tool. With it, three men have been able to clean a very considerable amount of large sewer pipe which was from 15 to 30 ft. deep, with manholes located from 400 to 700 ft. apart.

In principle, of course, the sewer hoe is the forerunner of the sewer scooter. It is, in reality, a moving dam that impounds the sewage until hydraulic pressure forces the dam to move forward. When the hoe has piled up sufficient debris in front to stop its downstream progress, the sewage builds up behind it and overflows the crest, or top, of the dam and digs out the sand and sludge in front of the hoe with its waterfall-like action. When this water has cleared a little space, the pressure behind the hoe forces it forward again. This push-wash action is continued until the foreign matter is carried to the lower manhole, where it can be removed. A ⅜-in. steel cable was used as a tail rope to control the hoe. This passed under a manhole jack in the upper manhole to a hand winch which is needed to hold the hoe back when it is desirable to stop it just before it enters a manhole.

Incidentally, since the Little Rock sewer manholes have 24-in. rings and covers, the sewer hoe had to be made so that it could be lowered through a circle about 22 in. in diameter. Figure 1 shows how this was accomplished.

Operation of Sewer Hoe

In operation, the various parts of the hoe are passed down into the manhole at the upper end of the run, and as-

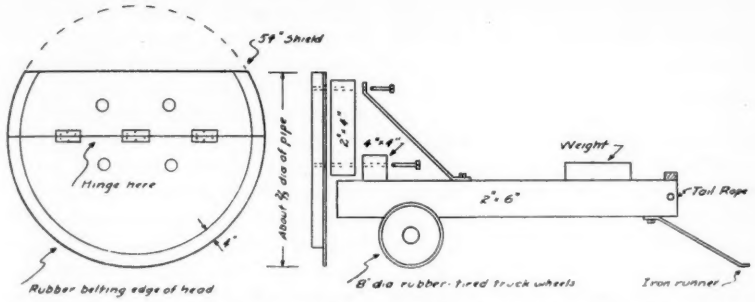

FIGURE 1.—Sewer hoe developed for cleaning 36- to 60-in. diameter sewers, Little Rock, Arkansas.

sembled. The hoe shield is not taken off until the end of the run of that particular size pipe. When a new size is encountered, the old head is passed out of the manhole, and the new size head lowered in, and fastened in place.

About 75 ft. before the hoe reaches the manhole below its starting point it is slowed down, as the debris is usually starting to appear in the manhole. A man is placed in this manhole, and starts loading the debris into a bucket which is hoisted to ground level. As he cleans out the sludge, the hoe is eased off, and a continuous stream of material is gradually brought into position for hoisting to ground level. At night the hoe is tied up in the sewer.

With excessively deep manholes, a bucket machine was used for hoisting the muck to ground level. This home-made machine proved most effective when used in this manner, as its 18-in. bucket hauled a good load to the surface with each trip.

Besides rocks, pick heads, and the usual miscellaneous junk that finds its way into a sewer system, an average of about 2 to 3 cu. yd. of fine sand and gravel were obtained between each succeeding manhole in the large sizes (42 to 60 in.).

A somewhat humorous note was injected into the cleaning routine following a torrential rain that occured while the hoe was tied up over night. Just as the men started their morning inspection to see if the infiltered water had subsided enough to enable them to go on with their work, a cable clamp (wasn't tight enough, of course!) gave way, and the 54-in. scooter really went a-scootin' with millions of gallons of water at its back. The men rushed to a spot about a halfmile away where the sewer made nearly a right angle turn in the manhole. By the time they had gotten the stud bolts out of the water-tight manhole cover, the hoe had passed with a bump-bump-bump as it went over each joint of pipe. The men managed to fish out the 500 ft. of cable that was being used as a tail rope, but were unable to hold it. One of the colored boys exclaimed: "Mr. Clapham, that thing went by here like a freight train highballin' through a crossin'!"

To capture the runaway, the gates at the lift station were closed, thus impounding the water and equalizing the pressure before and behind the hoe. Then, by opening the gate a little the speed of travel of the hoe could be controlled. Rather than hoist the hoe out of the 35-ft. manhole at the lift station, it was allowed to go to the river (about an additional 300 feet). Fortunately, the sewer outlet was not under water at the time, and "Old Faithful" could be dragged up the bank, after it had made a record run of two miles in less than eight hours. Needless to say, the shield was battered and has been retired, as is fitting for

all old work horses who have more than earned their keep in the service of the public.

Conclusions

Here in Little Rock the scooter and the sewer hoe have been found to be valuable parts of the sewer cleaning equipment. If any municipality has sizeable sewer lines to clean, which are still working at all, the writer would recommend the purchase of a sewer scooter and the construction of a sewer hoe.

There may come a time when like Old Black Joe, "we'll lay down the shovel an' de hoe." Maybe so, as far as the shovel is concerned, but the writer would still like to have a "hoe" handy. With it the Little Rock three-man sewer crew has cleaned 17,500 ft. of 60-in., 7,000 ft. of 54-in., 8,500 ft. of 48-in., and 7,200 ft. of 42-in. sanitary sewers, which is plenty of sewer!

BARK FROM THE DAILY LOG

By Walter A. Sperry

Superintendent, Aurora (Illinois) Sanitary District

November 14—If some archaeologist in the distant future should make a study of our then ancient sewer systems, the trinkets which would be found would be an amazing commentary on life as we live it. An anonymous lady called today for help in recovering a ring which had been dropped into the toilet. We explained, kindly and at length, the difficulties involved in recovering such an item. The ring was of platinum and was set with 22 diamonds. It was valued at $2,200.

November 17—It wasn't funny, but it was satisfying to finally find out what had happened to the ball valve that so mysteriously disappeared a year or so ago. A sludge pump is located between the Dorr clarifiers No. 2 and 3. While cleaning and painting the sludge collector of clarifier No. 3, we discovered that the sludge rakes at the base of the center column were twisted and bent. A complete new set was necessary.

After removing the rakes and while cleaning the channel beneath, we found our ball. Undoubtedly it had reached the clarifier as the result of an accident, but no one would ever admit it. This happens at every plant.

November 26—Here is another chapter in the life and adventures of our exhaust exchange heater (This Journal, **18**, 3, 539). We have always known that its location in the system was wrong, but the work and expense of changing it did not seem justified. It is located at the outgoing end of the muffle, and it runs too cool. We retubed it in 1945 by rolling in Byers W. I. pipe. At that time our welder seemed confident that it would last 7 years, but by the middle of 1947 it had developed a leak. A little welding repaired it, but our welder was dubious that it would last much longer.

We began to make comparative corrosion tests on various available types of metal against the day replacement of the heater would be required. Then we had a hunch. Heretofore all efforts to keep the temperature above the dew point—130° F.—had failed. This was because the volume of gas used by the engines varied with the high and low flows between day and night. At the same time all efforts to control the temperature by valve adjustment failed because of the fluctuating gas use and our inability to get sufficient throttling adjustment with 4-in. valves. Why wouldn't a Powers regulator valve act as a robot to automatically keep the valve in adjustment?

The representative of the valve company we consulted was a little doubtful, but finally decided that it might work; and it did—beautifully.

A 3-in Powers Reserve-Action No. 11 temperature regulating valve was installed on the bypass line. After some valve adjustment, we have been able to keep the temperature in the tubes at an average of 140° F. for a month. The day-night variation is not more than 7°, and the low at night is still above 130° F. During the day it is often above 150° F. On opening the heater we found the interior dry—a good sign. It looks therefore, like this may be the concluding chapter of this particular story.

December 12—Probably because sewage plant operators are in a nonprofit work and are devoted to the public welfare, there is a fraternal spirit of helpfulness among them that is a constant source of gratification to your Logger. Sewage works operators have no trade secrets.

Recently our B.O.D. dilution water showed too much loss after the 5-day incubation. We had been using tap water as a substitute for synthetic dilution water. After some days of parallel tests both waters showed too much loss. Careful cleaning of all apparatus also failed to improve the situation. About then we attended the Executive Board meeting of the Central States Sewage Works Association in Chicago, and at dinner we stated our problem to the group. Immediately L. S. Kraus, chemist of the Greater Peoria (Illinois) Sanitary District, suggested ammonia as the probable cause. This was the clew we needed.

Out of the instructive round-table that followed, we decided to adopt as standard procedure at Aurora the use of azide and the pasteurization of filter effluent and final effluent samples. We pass the ammonia suggestion along. It may solve another's dilemma.

December 10—As a corollary to the question of how to eliminate ammonia from dilution water, we now feel that our decision to abandon the batch type of still, with its worm and cooling tank, in favor of an automatic Stokes type of wall still was unwise for our type of laboratory. We are soon to resurrect the old pot still and worm from the attic, and set it up in another part of the plant. So far we have been unable to get ammonia-free water from our automatic still. The pot still can be treated with acid and at least a portion of its run obtained ammonia free. We will report on this matter again in a future column.

December 22—Misinformation about septic tanks continues to amuse, amaze, and now irritate us. We cannot resist sharing the accompanying gem of pseudoscience. While enjoying our noonday sandwiches, along with Toynbee's "A Study of History," the door opened and a man barged in we could not quite place till he began to talk about septic tanks. We remembered, then, that some months before we had given him a long and careful discussion about septic tanks, and hoped we would never see him again. Today he asked that we comment on his sales letter for B— S— Drain Cleaner and Sterilizer (simon pure caustic soda).

We quote from this remarkable letter: "The accumulated greases in your sewer pipes and tanks has killed the bacteria, and the foul condition inside keeps new bacteria from hatching, so the accumulation of solids has clogged your tank and has possibly even caused it to back into your basement. . . . Eight cans of B-S-P-C and S will liquify the greases, causing them to flow away, and will 'eat up' the accumulated solids, which jam the outlet, and will freshen the foulness which is killing the bacteria action, and then B-S P-C and S has done the $40 job for $4, and cleaned every thing, new solids enter the tank and bacteria action sets up again, and your job is done without digging or hoisting the tank at all. . . . This advice

comes from a national authority on septic tanks and their functions, whose editorials are solicited by countless magazines and periodicals on the subject all over the U. S. A."

We should have thrown him out, but our teaching instinct was too strong. We tried again to help him.

December 29—More trouble! Our secondary sludge pump, down on the river, is a 4-in. Marlow ball-valve pump, PE Simplex type, with an air chamber and a pressure gage on the discharge side. For some time this pump has been delivering at only half capacity. The piston was turned down and new Chevron packing installed. A new gasket was placed at the bottom of the pump cyinder. New ball seats were purchased and put in place. All of the valves were repacked and the 970-ft. discharge line was well backflushed. All of this work was to no avail.

Correspondence with the Marlow Company brought back an interesting and helpful letter from their Mr. A. C. Stratton. Mr. Stratton pointed out that—"A true picture of what is happening in the pump can hardly be gained from the pressure side of the pump. We think you will get the answer quicker by using a vacuum gage on the suction side." He goes on to say, "If the vacuum reading is high, say in excess of 15 to 18 ft. average, the suction line is probably clogged. If the vacuum does not build up to say 12 to 15 ft., excessive air or gas is present."

We are satisfied that there is no gas interference from the sludge. We are also reasonably sure that the suction line is not blocked, although there is some suspicion that snail shells have washed over from the filters into the sludge pit beneath. This will mean pumping down the tank as soon as weather permits. In the meantime, we strongly suspect that there is an air leak in the line, but as yet have been unable to find it. This story will have to be continued.

January 7—We entertained the first distinguished foreign visitor of the year today in the person of Dr. Anilo Batini, Minister of Public Health, Rome, Italy. He was the guest of Dr. Felix Tornabene, Director of the District No. 5 office of the Illinois Department of Public Health, here in Aurora. Dr. Batini spoke Italian, French, Latin, and German fluently, but was not so at ease (yet) with English.

Thanks, however, to Dr. Tornabene's ability to speak Italian, we succeeding in giving our visitor his first opportunity to learn something about an American sewage treatment plant. He seemed much impressed with the idea of the gas engines. He was plainly astonished when we told him that our daily flow was approximately 24,000,000 liters. We can well imagine that Italian water supplies do not provide water as lavishly as those in the United States.

January 13—We are indebted to Mr. R. A. Seidenstricker, Chief Engineer, Process Equip. Div. of the Chain Belt Co., for an interesting comment on shear pins that grew out of some problems on the secondary settling basins.

We quote in part from Mr. Seidenstricker's letter: "On sewage treatment equipment the torques are relatively low so that it would not be practical to use steel shear pins, as the size would become so small as to be impractical. Furthermore, when a steel shear pin is used it is necessary to surround the shear pin with a hardened steel bushing, as the cast iron into which the shear pin is installed does not afford proper support for a steel pin, resulting in breaking of the cast iron around the shear pin hole when the pin shears. Accordingly, we have adopted an aluminum shear pin because it is softer and shears at a lower torque value, and because when shearing it does not destroy the cast iron." He goes on to state that while

copper made a fair substitute for shear pin use during the war years, No. 3 SH aluminum rod of the right diameter is preferred material.

January 24—The huge wall paper printing plant just across the tracks from our plant is now is full operation. While helping to tune up their small chemical precipitation waste treatment plant we made some peculiar discoveries as to the best way to coagulate their waste. This waste is a mixture of casein, protein, clay, color bodies, and alkalies, running from 11,000 to 14,000 p.p.m. suspended matter, which is carried in 50,000 to 100,000 gal. of water per day. The waste pH value averages about 9.0.

If the pH was adjusted from 9.0 to 7.0, about 40 grains per gal. of alum were required for good coagulation. If the pH was not adjusted, however, 80 grains per gal. of alum were required. Ferric salts gave no coagulation effect at all. Ferrous iron gave excellent coagulation if the pH was adjusted with calcium hydroxide to about 11.0, but 100 grains per gal. were required. If the pH was adjusted with sodium hydroxide, the amount of ferrous iron required doubled.

Quite by accident, when too much acid was added to adjust a batch of waste to pH 7.0, the material coagulated sharply and without any coagulant present. We determined later that the pH had been adjusted to about 5.0. On looking up the subject we found that protein and casein precipitate when the pH is adjusted to the proper acidity. The isoelectric point for protein is at pH 4.8. The simple addition of the proper amount of acid, therefore, did the trick, producing an almost clear effluent, and in an amazingly short time. The problem for management, then, changes from that of the purchase and use of alum to the problem of preventing corrosion resulting from the high acidity of the waste following precipitation.

February 2—At the January board meeting our Sanitary District trustees opened bids and awarded contracts for an interesting new addition to the equipment of our plant. The sludge collector is to be removed from the north clarifier and aeration equipment installed. The tank will be so modified that it can receive all the screen and grit chamber flow for aeration before passing to the three primary clarifiers. Since only two clarifiers are ordinarily used, this leaves one clarifier in reserve.

The equipment is of the diffused air type and will consist of two diffused air assemblies of the impinger type, with forty impingers each, two Root-Connersville blowers, and two impinger pumps. Aeration is being added to the process primarily to control odors arising from the filter sprays, especially on summer evenings. In addition, grease will be concentrated, and some flocculation of suspended solids is anticipated. Thus, several new and interesting laboratory studies are ahead and possibly another story for this Log will develop.

February 28—Here are some examples of the extra-curricular jobs for plant superintendents which are associated with plant supervision: November 25—Two high school chemistry classes were given our standard plant lecture and conducted tour; December 12—Gave a long-form lecture and conducted a plant inspection tour for an attractive group of nurses from St. Joseph's Hospital; January 5—Addressed the local Lion's Club on the history and development of the Aurora Sanitary District; March 7—Entertained the Lutheran Married Folks Club—some 60 odd—with a lecture and plant inspection Sunday afternoon.

ALKALINITY CONTROL OF THE TRICKLING FILTER PROCESS AT VIRGINIA BEACH

By A. W. Petty

Sanitary Engineer, Virginia Beach, Va.

The Virginia Beach, Va., sewage treatment plant is probably rather unique in that the method of treatment control was originated on the premises. By effecting careful chemical control of the trickling filter influent, a heavily overloaded plant with an unsatisfactory effluent was made to remove 96.5 per cent of the raw sewage B.O.D. and to produce an effluent which, in clarity, almost rivals the local tap water.

Plant Description

The plant consists of pre- and post-chlorinators, bar screens, grit chamber, two primary clarifiers, a flash mixer and flocculator (for chemical treatment), secondary clarifier, dosing tank, trickling filter and final clarifier, two-stage digesters, drying beds, and various appurtenances. The flow varies from 0.3 m.g.d. in winter to 1.25 m.g.d. in summer, exclusive of heavy infiltration during protracted wet spells. In order to save construction costs the filter was designed for the winter flow, with chemical treatment without filtration to be used during the summer. The plant was completed in 1938 at a cost of approximately $170,000, and about $4,000 was spent in recent years on remodeling. J. E. Gregory is plant superintendent, and Ben Gregory laboratory technician.

Plant Rehabilitation

When the writer began operation of the plant the situation was rather discouraging, to put it mildly. There was a foul, septic influent to be treated, a small outlet ditch with practically no dilution water in which to discharge the effluent, and, due to lack of personnel and available replacement parts during the war, a run-down plant with which to do the job.

Procurement of new operating personnel was the first step. A capable and efficient plant foreman able to do a real job of maintenance was first obtained. His son, with only a high school education but with plenty of enthusiasm, was developed by the writer, under the G. I. training program, into a Grade A operator and laboratory technician. A couple of strong and willing colored boys completed the squad.

Under the rehabilitation program new bar screens, a new flow meter, and a new chemical feeder were installed. The unsatisfactory dosing siphon and a badly corroded and worn out filter distributor were replaced. Clarifiers, pumps, digesters, and other equipment were put in good working order. Sufficient prechlorination equipment was installed at the central pumping station to deliver to the plant fresh sewage, minus odors and amenable to treatment.

Unsatisfactory Operating Results

However, even with things in good condition the plant wouldn't give the desired results, using standard procedures. A polished effluent was necessary due to the small dilution available in the outlet stream and the existance of extensive sludge deposits along the stream bed below the plant outlet.

The answer, according to all the books and expert advice, was more plant, particularly filter volume. However, this would have cost money which was not available, so the only alternative was to make the available treatment units work.

Full credit must be given the plant designers who, unable to predict exactly what might happen in a com-

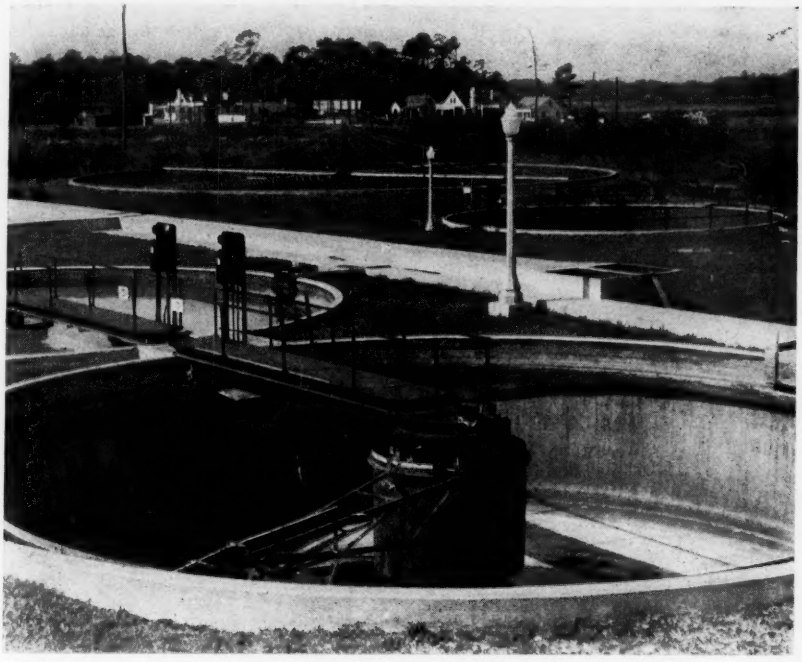

FIGURE 1.—View of clarifiers and trickling filter, Virginia Beach, Va., sewage treatment plant.

paratively new and growing community, designed a very flexible plant which could be operated in many different ways. Since none of the old ways appeared satisfactory it was up to the writer to try something new.

Seasonal Changes in Operation

When the filter is used the plant will handle the low winter flow of about 1.5 m.g.d. without flooding. Supposedly, the high summer flows of 3.0 m.g.d. can be given primary and chemical treatment by bypassing everything beyond the secondary clarifier. However, straight chemical treatment is expensive and while it does provide good solids removal, the B.O.D. reduction is poor. If the filter is not operated during the summer, the growth, of course, dies and must be restarted again in the fall. Further, a good effluent is practically unattainable if the filter is used without the aid of chemical treatment.

Chemical Flocculation

Various chemicals had been used for floc formation, but without much success. The alum floc generally formed nicely but settled poorly, and the effluent looked strangely like the influent. In experimenting with pH adjustment with lime, it was noted that lime alone gave better clarification, and with less expense, than a combination of lime and alum, so precipitation with lime was adopted.

Filter Growth Changes

It was also observed that when chemical treatment was used with the filters in the summer and then discontinued during the winter, the filter growth died following each change in operation. This, undoubtedly, was due

to the change in the chemical characteristics of the sewage effected by the lime. It was then decided to attempt to find the optimum chemical condition, from a standpoint of pH and alkalinity, under which the best filter growth could be maintained and the best effluent could be produced.

The wrong beginning was made in looking for this optimum point. A heavy lime dosage was first used and then successively reduced. The reason for this was that while replacing the filter distributor, straight chemical treatment with lime was used. After the filter was placed in operation the lime dosage was tapered off in an attempt to find the condition for optimum development of filter growth. The result was a heavy lime deposit on the filter stone.

At the suggestion of F. H. Miller, Virginia Dept. of Public Health, it was decided to remove the lime deposits by the use of alum, and start with small lime additions in trying to find the pH and alkalinity range for maximum filter efficiency. Alum was used to remove the lime deposits, 2 tons being applied in 2 days.

Alkalinity Control

The final answer to the problem of finding the pH and alkalinity range for optimum filter operation was discovered to be the conversion of bicarbonate alkalinity to carbonate alkalinity. Usually the bicarbonates in the raw sewage vary from 50 p.p.m. in winter to 125 p.p.m. in summer. After primary treatment, sufficient calcium hydroxide is added to the settled sewage to produce carbonate alkalinity. The insoluble carbonates which form settle in the secondary clarifiers, sweeping out much of the remaining fine solids. (This does not preclude the Rudolf's theory that complex phosphates form a floc ahead of carbonate formation.) Normally, if insufficient lime is added to convert most of the bicarbonates to carbonates, the filter is inefficient and a dark unstable effluent results. Under such conditions the filter growth appears more nearly like the normal black standard filter growth.

If, however, the bicarbonates are practically all converted to carbonates, an efficient growth is maintained on the filter and excellent results are obtained in B.O.D. and color removal. The resulting filter growth is usually bright green, although sometimes spotted with black or other colors. On the other hand, if too much lime is added and the hydroxide alkalinity range is entered, even a few p.p.m., the filter growth begins to die and slough off, and lime will begin to deposit on the filter stone. There is one exception to the above since the hydroxide alkalinity tolerance of the filter seems to vary with the temperature, being much higher in the summer.

Having finally worked out this method of control in the winter of 1945–46, excellent results were obtained until July and August 1946 when plant efficiency dropped a little. It was assumed incorrectly at that time that even with the use of alkalinity control the plant couldn't quite handle the peak summer load, and that the filter growth would be damaged if the load was increased. In the fall the filter efficiency again picked up and things went well until July 1947 when efficiency again began to fall off.

Hydroxide Alkalinities

In July there was also trouble with an unfavorable growth and ponding on the filter. It was decided to try to eliminate these by adjusting the alkalinity to the hydroxide range, even if a large part of the filter growth was lost. It was happily discovered, however, that not only were the undesirable filter growth and ponding eliminated, but that the green filter growth which produced the high filter efficiencies, and which was damaged by even slight hydroxide alkalinities in cool weather, actually thrived in the hot sunny

TABLE I.—Summary of Operation Results, Virginia Beach Sewage Treatment Plant, October, 1946 to September, 1947

	Oct.	Nov.	Dec.	Jan.	Feb.	Mar.	Apr.	May	June	July	Aug.	Sept.	Average
Average Daily Flow (m.g.)	0.365	0.355	0.294	0.410	0.396	0.519	0.575	0.538	0.860	1.076	1.119	0.976[1]	0.624
Average Daily Lime Used (lb.)	685[2]	535	435[2]	415[2]	457	660[2]	730	882	1310	1540	2492	1607[2]	981
Average Daily Settleable Solids (ml. per 1,000 ml.)													
Raw	5.0	5.6	4.8	4.2	6.1	6.5	4.8	6.7	6.9	6.7	6.9	5.3	5.8
Primary	0.3	0.9	0.0	0.1	0.1	0.1	0.2	0.1	0.2	0.2	0.2	0.2	0.2
Flocculator	7.4	4.5	5.1	3.3	5.4	4.8	4.1	7.0	6.5	5.8	8.9	7.8	5.9
Secondary	0.3	0.0	Trace	Trace	Trace	Trace	0.1	Trace	0.1	Trace	0.1	Trace	0.1
Filter	0.2	0.4	0.2	0.5	0.2	1.7	1.3	0.4	0.5	0.1	0.2	1.3	0.6
Final	0.2	0.1	Trace	0.1	0.1	0.8	0.2	Trace	Trace	Trace	Trace	0.2	0.1
Average Daily Suspended Solids (p.p.m.)													
Raw	150.0	184.0	120.0	136.0	179.0	185.0	190.8	199.0	153.4	185.0	182.5	146.4	167.6
Primary	73.0	68.7	74.0	66.2	68.0	80.3	64.0	54.0	63.4	77.0	73.0	68.2	69.2
Secondary	42.0	25.0	39.0	36.5	27.0	34.8	36.0	25.0	30.8	31.0	25.0	33.6	32.1
Filter	18.5	26.0	24.0	30.1	17.0	15.0	30.0	20.0	14.0	12.0	13.0	20.3	20.0
Final	17.0	14.0	13.0	18.6	12.0	8.8	14.0	12.0	8.4	9.4	10.7	10.4	12.4
Average Daily Relative Stability (%)													
Filter eff.	99	99	98	97	99	97	97.5	99	99	68[3]	80[3] 99[4]	98.5	94.3

[1] Pumping station out, flow off 2 days.

[2] Lime dosage not recorded on one or more days during month. Average based on number days reported.

[3] Prior to entering hydroxide range (average for full months).

[4] After entering hydroxide range (average for last part of month).

weather under hydroxide alkalinities of as much as 50 p.p.m. Plant efficiency returned to winter averages. At the conclusion of the summer season load and with the return of cool weather the practice of adjusting the alkalinity to the carbonate range was resumed.

The great advantage of alkalinity control is that while other tests show what is happening or has happened, the alkalinity tests show beforehand what will happen several hours later.

In order to take care of the variation between night and day flows the lime feeder must be adjusted at least morning and evening. These adjustments depend on results of alkalinity tests during the various flows. Usually an excess of 10 p.p.m. bicarbonates calls for an increase in lime dosage while the presence of any hydroxide requires a decrease in dosage.

Operation Control Tests

The pH picture through the plant is interesting. The raw sewage varies from 6.7 to 7.3, usually between 6.7 and 6.9. Application of the lime raises the pH to about 9.6 in winter and to above 10.0 when entering the hydroxide range in the summer. Through the filter the pH drops back to around 7.3 to 7.5, and the final effluent pH is about 7.0 or 7.1. The pH tests are run with each test for alkalinity.

Methyl orange and phenolphthalein are used in alkalinity tests, and the results—hydroxide, carbonate, and bicarbonate—are expressed in terms of calcium carbonate, according to Standard Methods.

Daily and monthly records of flows, chemicals used, and all laboratory results are recorded. Routine tests other than pH and alkalinity include settleable solids, suspended solids, turbidity, stability (methylene blue), and residual chlorine. Table I presents a summary of results.

Analyses of samples taken during the peak load month of August, 1947 by William E. Bell, of the State Department of Health, gave the following results:

Average daily flow (m.g.d.)	1.1
Raw sewage, ave. B.O.D. (p.p.m.)..	215
Primary effluent, ave. B.O.D. (p.p.m.)	138
Trickling filter effluent, ave. B.O.D. (p.p.m.)	11
Final effluent, ave. B.O.D. (p.p.m.)	5
Overall plant removal, per cent.....	96.5 *
Final effluent D.O. (p.p.m.)	2.40

The lime dosage varied from 100 lb. per 100,000 gal. in winter to more than 200 lb. per 100,000 gal. during the past summer when it was necessary to go up into the hydroxide range for a few weeks. On the other hand, straight chemical treatment without use of the filter required up to 400 lb. per 100,000 gal. for a fair effluent.

Use of Prechlorination

Sufficient chlorine is added ahead of treatment to carry a trace through the primary clarifiers during the summer. In cold weather only a slight residual in the plant influent is necessary. A residual of 0.1 p.p.m., or more, is maintained in the final effluent by post-chlorination. While chlorination is essential to proper plant operation due to long sewer lines and flat grades, it is about the most expensive item of treatment. A part of the sewage from a nearby Army Camp travels over 6 miles before reaching the plant. The town itself is 47 blocks long, although only a few blocks wide at its narrowest point. During hot weather it is necessary to use 200 lb. of chlorine per day for prechlorination.

Control of Chlorination

Control of prechlorination is very important. An insufficient dosage not only results in odors and poor sedimentation in the primary clarifiers, but also results in the growth of unfavorable organisms on the filter, particularly when contractors engaged in cleaning septic tanks haul many loads to the plant. On the other hand, overdosages of chlorine prevent proper filter growth.

It is interesting to note that while, of course, not as accurate as the comparator and burette, the eye and nose are good indicators of proper chlorine and lime dosage. Under-chlorination gives the raw sewage the typical color and odor of septic sewage, while a residual of 1.0 p.p.m. will cause a milky color and medicinal odor. A clear secondary effluent and the smell of lime on the filter indicate hydroxides; a cloudy secondary effluent and a spetic smell at the filter indicate excess bicarbonates; while a slightly cloudy effluent and fresh "green" woodsy smell indicate good results. A sharp eye and a keen nose are vauable in that when the flow varies more than usual, they will indicate the need for additional control tests.

Lift Station Failures

The most vexing problem still remaining lies in the failure once or twice a year of the central pumping station due to a breakdown or power failure. Since the total flow passes through this lift station to the plant, this failure if lasting as much as 24 to 48 hours causes the filter growth to dry and die. When operation is resumed it takes 2 or 3 days for most of the dead growth to wash off and out of the filter. New growth begins to appear in about the same length of time and the filter returns to normal in from a few days to 2 or 3 weeks, depending on the weather. The new growth is usually spotty, gradually spreading out, and in its early stages is yellow, brown, pink, and sometimes blue. Gradually green spots begin to appear and finally a bright green jelly-like growth, with occasional black spots, covers the filter. The black color is more predominant with a lower carbonate alkalinity, the green with the higher. The plant and animal life of this filter would present an interesting problem to the biologist.

* Averages of raw and settled sewage B.O.D. contain several samples not included in filter and final effluent averages. Overall plant removal calculated from daily percentages of overall removal and not on values given above.

Filter flies, which are not active when hydroxides are present for any length of time, will become a nuisance otherwise unless controlled. While no attempt is made to eliminate them, they are kept from becoming a nuisance by spraying the filter curb and the grass around the curb with DDT.

One problem created by this type of treatment is that of sludge disposal. The plant digesters have too little retention during the summer, but the sludge dries satisfactorily and has only a little odor in the immediate area of the drying bed. Gas formation is retarded and foaming apparently is a thing of the past.

Summary

The type of treatment and treatment control used at the Virginia Beach plant would be of little value to primary treatment plants or secondary plants having a constant load. The writer believes, however, that designers of new plants which would have a variable seasonal load would do well to consider the economics of the additional cost of providing for alkalinity control as against that of larger secondary units. Certainly existing overloaded plants, particularly where the overload is seasonal, might find alkalinity control to be a life saver.

While proper maintenance, good general operation, and attention to detail are as essential at the Virginia Beach plant as at any other, the key to a near perfect effluent has been the maintenance of adequate prechlorination and the proper control of settled sewage alkalinity.

TIPS AND QUIPS

From Jam to Jelly

C. E. Corrington, superintendent of the Clinton (Ill.) Sanitary District, deserves a hand for turning a grounds maintenance problem into a neat bit of good public relations practice. When the Cinton treatment plant was built, a long, double row of crab apple trees was planted as a landscape feature for a portion of the plant grounds. The trees prospered, and the long rows with the wide grassy area between them have added materially to the appearance of the plant.

The apples from the trees are another matter, however, and have always created a collection and disposal problem in the fall. Unless picked when ripe, they must be raked up each time the grass is mowed. And as most sewage works men will understand, Corrington has had little time to spare for apple picking.

Faced with the problem of disposing of a particularly large crop of crab apples last year, Corrington hit upon the happy idea of giving them away—for the picking! A small ad in the local paper brought out the bargain-wise womenfolk of the community with pails and baskets and boxes. In short order the trees were picked clean and even many of the culls which had already fallen were salvaged. All of the apples except the juice soon came back to the plant, of course, but as Ray remarked, "Apples are more easily pumped than raked."

Crab apple jelly, courtesy of the sewage treatment works, was a familiar breakfast item in Clinton last winter. So far as we know, this is the first sewage works byproduct to land on America's breakfast table!

Contribution from Cleveland

John J. Wirts, formerly superintendent of the Cleveland, Ohio, Easterly sewage treatment works, has responded nobly to the plea for operating tips. His contribution consists of sketches of the inlet and outlet junction chambers for the sludge force main which

connects the Easterly plant with the Southerly plant. All raw primary sludge and all waste activated sludge collected at the Easterly plant is pumped to the Southerly plant for digestion and disposal.

These sludge junction chambers were constructed to permit easy insertion and removal of a pipe-line cleaning device for the sludge force main, regular cleaning having been proved necessary because of the tendency of the force main to gradually clog.

Mr. Wirts' comments on the sketches follow:

"The force main is a 12-in. dia. cast iron pipe, 13 miles long, and is capable of transporting one million gallons of sludge per day. The junction chambers, as shown, are used to inject and eject a cleaning machine into the main without taking the main out of service. Provision is made for applying hydraulic pressure behind the cleaning machine in the 14-in. pipe section and then by proper valving, as shown, the cleaning machine is forced through the reducer into the 12-in. main. Similarly, at the outlet junction chamber the machine is forced out of the line by way of a 14×12 reducer so that there is no necessity for excavation, dismantling, and reassembly of any part of the system.

"This same principle is readily adaptable to heat interchangers for sludge digestion when 6 in. diameter or larger pipe is used for the heat exchanger. This principle has

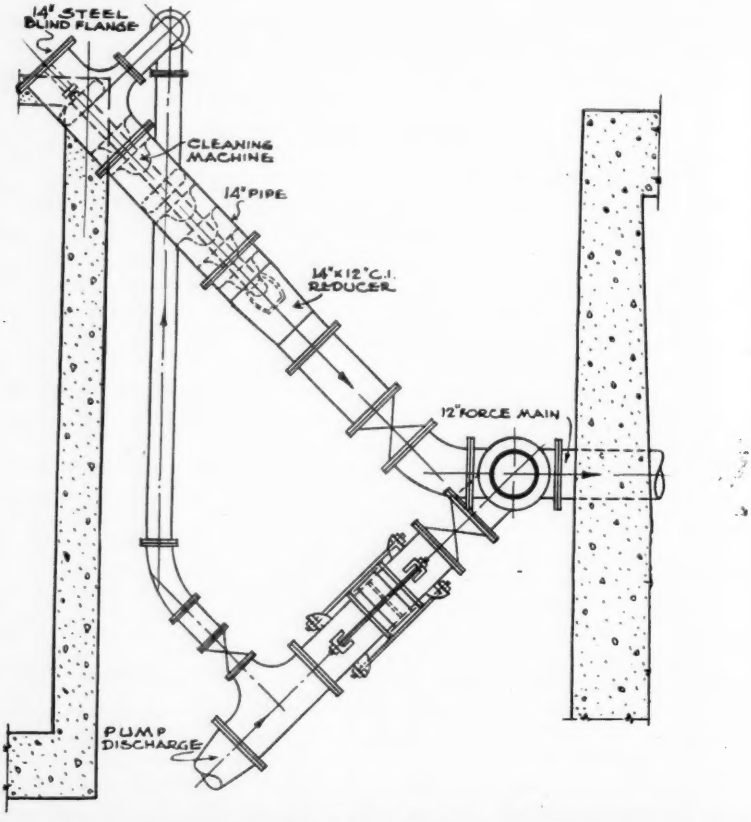

FIGURE 1.—Piping arrangement for insertion of sludge main cleaning machine, inlet junction chamber, Easterly Site, Cleveland, Ohio.

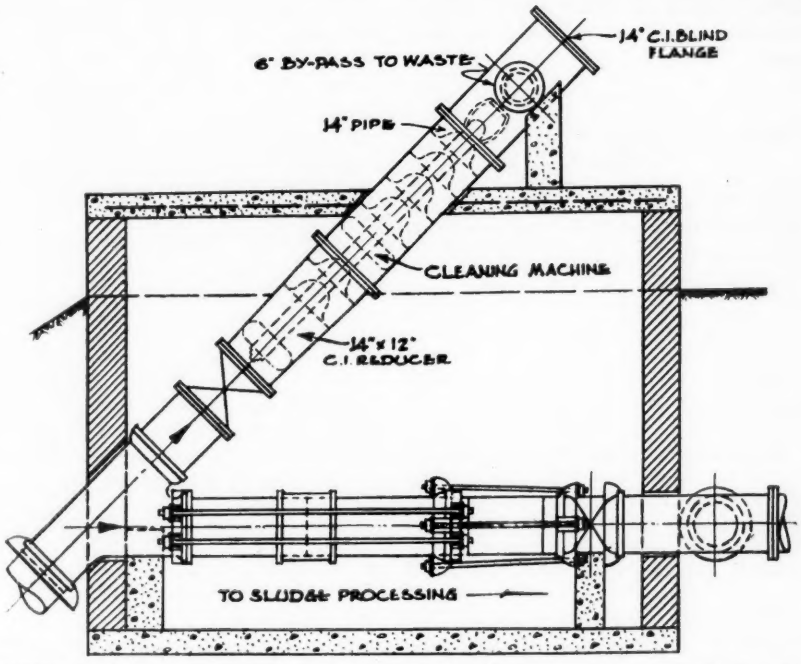

FIGURE 2.—Piping arrangement for removal of sludge main cleaning machine, outlet junction chamber, Southerly Site, Cleveland, Ohio.

been utilized in Cleveland for the past 5 years with complete success and at a considerable reduction in cost over the usual methods of pipe line cleaning.

"It is obvious that the junction chambers provide a means for cleaning the piping system in a matter of hours rather than days. This feature is important when there is no alternate provision for alternate or standby piping."

This One Will Take Your Breath!

Our award for the best sentence seen anywhere yet this year goes to the following one by Tom Powers, high-geared president of the Michigan Sewage Works Association. It comes from Tom's presidential report in the February Michigan Sewage Works Bulletin. We quote:

"What with the Federation meeting scheduled for Detroit in October; an aggressive educational committee working hard on a special program of in-service training at the School of Public Health at the University of Michigan in 1949 and a joint program with water works men covering fundamentals such as hydraulics, basic and advanced chemistry, bacteriology, water works engineering, biology and a newly instituted course of industrial waste treatment and stream sanitation, in addition to our regular short course at Michigan State College; an infusion of new talents from members of industry; a half dozen or so research programs; the highest membership in the history of the association; not to mention the completion of the most ambitious program of planning of municipal facilities in the history of the state; *things are indeed looking up.*"

Well! We would say so, too. If reading that sentence won't take your breath away, reflecting on what this ambitious association is doing surely should serve as a starter. Grammatically, the sentence may not be so hot,

but as a mark for other member associations to shoot at, it's a good sentence!

Removing Sludge from Digester Coils

All operators who have resigned themselves to the necessity of pumping down digesters for inspection and/or repair of heating coils—and may their number be few—might make a mental note of the suggestion on digester heating coil cleaning relayed by Frank Woodbury Jones, the mentor of the Quarter-Century Operators' Club.

"To facilitate removal of caked sludge, they run hot water through the heating coils after the coils are exposed, so as to bake the sludge on the coils as much as possible. The caked sludge is then removed by knocking it off with a hammer."

The "they" mentioned above refers to Walter Gerdel and G. E. Flowers, superintendents of the Cleveland Easterly and Southerly sewage plants, respectively, who have used this method with good results. As far as we know, these Cleveland stalwarts have no past, present, or future patents, pending or otherwise, on the idea, and it may be used without posting a guard at the gate or barring equipment sales representatives from the grounds.

Up! Up! Up!

Seven hundred and fifty feet isn't long for a sewage force main, as force mains go. But when the 750 ft. is all vertical distance—straight up—it's something unusual.

Carlsbad Caverns National Park, in southwestern New Mexico, is a connected chain of spectacular caves, located 750 ft. below the surface. With visitors totaling up to 4,100 per day, sewage collection becomes a necessity, and, 750 ft. below ground, disposal is somewhat of a problem.

For many years collection was provided by metal can receptacles, located in pit toilets. Disposal was by manpower—via the elevator—after the day's activities were over. This arrangement must have been one of the first, and surely the highest, sewage lift station arrangements which did not utilize pipes or pumps.

In 1940, however, convenience and convention won out, and a water-carriage collection system was installed. All sewage from concessioner's facilities (lunch room, etc.) and from the rest rooms is collected by gravity in a 10,000 gal.. sump. From the sump sewage is lifted 750 ft. to the surface through a 3-in. pipe line, located in the elevator shaft, by electrically driven pumps having an operating capacity of 50 g.p.m. Disposal at the surface is accomplished by discharge into an arid side canyon located about 3,000 ft. from the park.

C. M. Carrel, National Park Service, who described the Caverns sewerage facilities in the January, 1948 issue of the Arizona Sewage and Water Works Association bulletin, did not comment on operation problems encountered. With all that height of lift, though, we can't help but wonder about check-valve slam and pump-packing practices.

Portable Blower-Exhauster

Once again we break with an established practice of not presenting here announcements of new equipment releases. The newly developed "SAF-T-AIR" portable safety ventilator (Figure 1), however, promises to be an item which may have wide usefulness for sewage works ventilation purposes, particularly at the smaller installations. Sewage works ventilating equipment is not a new development, but little has been offered heretofore which combined capacity and portability in units which were adaptable to the

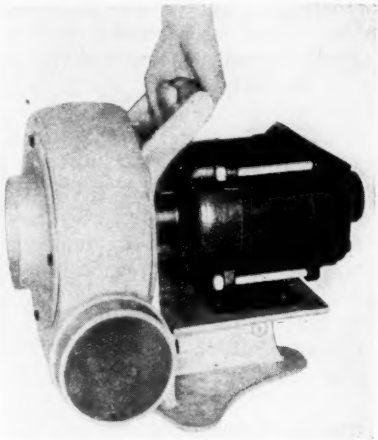

FIGURE 1.—"SAF-T-AIR" portable safety ventilator.

needs of the smaller sewage works systems.

"SAF-T-AIR" is described as a small but portable electric motor-driven ventilator, having a capacity of 425 c.f.m., yet with a weight of only 50 pounds. It is easily carried by one man because of its balanced handle, located over the center of gravity. Made of noncorrosive, sparkproof aluminum, "SAF-T-AIR" can be connected with the nearest lighting or power supply outlet without danger of overloading. Compact in size, it will pass through manhole openings and other small hatchways.

Adaptable as either a blower or exhauster, "SAF-T-AIR" is said to be excellent for eliminating hazardous gases, fumes, vapors, etc. from sewers, manholes, wet wells, and tanks. More versatile than stationary units, it is also claimed to be highly efficient on welding, spray-painting and tank-coating jobs.

Sewage works men will readily think of many practical uses for this portable blower-exhauster. Its size and simplicity should place it in a price range within the reach of even small municipalities.

Name of manufacturer will be furnished upon request.

Painting Propaganda

Sewage works superintendents and operators who have tried to explain the why and how of proper paint practices to uninformed, and sometimes unimpressed, plant personnel will immediately recognize the value of the recently released Navy publication "Brush Up on Your Painting." Although prepared on the premise that the comic strip level presents the best method of approach, this manual does contain basic, worthwhile information on surface preparation and painting practices, together with excellent suggestions on the care of brushes and other equipment. A discussion of spray painting is also included.

Perhaps the chatty and breezily illustrated makeup and style of the manual may irk the more serious minded members of the sewage works family, many of whom may still consider it sufficient to tell an employee what to do, without worrying about an approach-attitude, or method of motivation, or the psychological receptivity of an employee. And a case can be made for this viewpoint.

The fact still remains, however, that only men who want to will produce a good paint job. The Navy has probably trained more painters, and with less employee incentive, than any other employer, and it has given the less subtle employee-approach methods a century or more of trial. The distribution of a few copies of the Navy's paint booklet among your men prior to painting time just might prove worth while. At least the investment would be small, as copies of "Brush Up on Your Painting" (T.P. 17) can be obtained without cost by writing the Navy Department, Bureau of Ships.

Locating Submerged Pump Trouble

Submerged sewage pumps are used in many sewer system lift stations and at many of the smaller sewage treatment works. Invariably they are located in wet wells which have no provision for shutting off the sewage flow, which makes locating and correcting pump trouble a disagreeable job.

Although little can be done to eliminate the difficulty of making repairs with such pumping setups, a good deal of work and worry may be eliminated in locating pump troubles if the causes are thoroughly understood. Many sewage works men have found a check list of factors causing pump trouble useful in determining the reason for a particular pump failure. By means of a check list the search for the trouble can be systematized and the overlooking of any possible factor prevented.

Harvey Williams has prepared such a practical check list for submerged pumps which should prove helpful in running down causes of pump trouble. This list originally appeared in the July-August 1947, *Yoemans Guard*, and is as follows:

Locating Trouble in Submerged Type Pumps

By Harvey Williams

Preliminary

1. Turn current off and remove fuses.
2. Check fuses. Leave fuses out.
3. Try to rotate unit by hand. Shaft should turn freely.
4. Check incoming line for full voltage. All phases.
5. Check overload relay in starter. Push reset.
6. Check to see that all connections are tight at fuse box, starter, float switch, and motor. Also look for any defective wiring.
7. Reinstall fuses and try unit.

No Water Delivered

1. Wrong direction of rotation. Check with arrow on motor support or basin cover plate. Most pumps are right hand pumps and operate in a clockwise direction when viewed from motor end.
2. Speed too slow. When direct connected to electric motor, check whether motor is across-the-line and recives full voltage on all phases. Check motor connections. Check motor speed with tachometer and compare with motor name plate rating.
3. Impeller completely plugged up. Close gate valve on discharge line. Open check valve by removing cover. Start pump for a moment. If full capacity does not come out, either discharge line between check valve and pump is plugged or impeller is plugged. (On bilge pumps screen may be plugged.)
4. Discharge line plugged. If water comes out check valve in full quantity when checking Item 3 above, either the discharge line is plugged beyond check valve or the total discharge head is too great.
5. Impeller loose on shaft. This rarely happens on Yeomans pumps as they have keys and locknuts.

Not Enough Water Delivered

1. Impeller partly plugged up.
2. Speed too slow. Check line voltage and connections to motor. Check voltage at motor (all phases).
3. Discharge head higher than anticipated.
4. Discharge line partly plugged.
5. Leak in pump casing.
6. Leak in discharge line.
7. Impeller worn or damaged.
8. Impeller not set close enough to suction plate. (See Instruction Sheet for Unit.)

Not Enough Pressure

1. Speed too slow.
2. Head higher than anticipated. (Impeller too small.)
3. Impeller worn or damaged.
4. Leak in pump casing or discharge line.
5. Impeller not set close enough to suction plate.

Pump Takes Too Much Power

1. Speed too high. Check line voltage and motor connections.
2. Head lower than rating. Pumps too much water.
3. Mechanical defects.
   (a) Shaft bent.
   (b) Rotating element binds.
   (c) Stuffing box too tight.
   (d) Motor defective.
   (e) Impeller rubbing on suction plate.

Pump Noisy and Vibrates

1. Needs lubrication.
2. Motor not properly aligned to pump.
3. Air in liquid being pumped.
4. Motor bearing worn.
5. Pump bearings worn.
6. Pump shaft bent.
7. Impeller partly plugged causing it to be out of balance.
8. Cushions worn in coupling.
9. Parts loose.

Going . . . Going . . . ?

Of course, it could happen only in Southern California. Imagine taking off a manhole cover and finding only half a manhole opening! Investigation revealed that the rest of the opening was still there but that it had slid under the pavement, or that the pavement had slid past the manhole, or, since it was California, probably both.

Less mysterious but not less serious was the real reason. Subsidence was found to have occurred along the entire length of a 3,000-ft. line. At one place the sewer invert elevation was found to be more than 3 ft. below design grade. Subsequent elevations taken recently have reflected an even greater difference.

If anyone can advance a solution for this baffling probem it ought to be worth a lot of free orange juice. Seriously though, if ever there will be a place where water can be made to run up hill, it should be in Southern California!

OZONATED AIR FOR ACTIVATED SLUDGE

Pilot plant studies on the application of ozonated air in the activated sludge process were described at the 1947 Annual Meeting of the Ohio Conference on Sewage Treatment by Superintendent Carl A. Bauer of Celina, Ohio. Although the data secured during the studies were not significant because of the lack of facilities for metering flows of sewage, air and ozone, some interesting preliminary observations were made.

The pilot plant, employing metal aeration tanks having a total volume of 45 gal., was compared with the main Celina plant while treating a mixture of domestic sewage, cannery wastes, milk wastes and wastes from a stearic acid plant. Ozone was added to the air used for aeration in the pilot plant.

Treating a settled sewage ranging from 190 to 470 p.p.m. of B.O.D., the pilot plant yielded an effluent after 2 hours aeration that was comparable to that produced in the main plant after 15 hours aeration. Several times during the 10-week test run the ozonation was suspended, after which the mixed liquor in the pilot plant turned septic in 5 to 6 hours. Upon resumption of ozonation of the applied air, the mixed liquor returned to its normal condition within 6 hours.

Further studies with ozonated air are planned at Celina. This work is to be done on a plant scale, with adequate metering to insure reliable data.

Editorials

SYNTHETIC DETERGENTS AND SEWAGE TREATMENT

Shakespeare willing, it might be said that "The quality of sewage is not static. It changeth as the years bring better living." Witness the difference in the character of domestic sewage that has derived from paper products developed in the past 25 years, from today's trend toward household garbage grinders, that originated about 15 years ago, and from the recent upsurge in the use of synthetic detergents, which were all but unknown to the housewife before 1940.

Except for the spectacular eruption * of the Mt. Penn, Pa., sewage treatment plant the day after free samples of a new household-purpose detergent had been distributed from door to door, there has been little more than casual interest in this country concerning the possible effects of synthetic detergents on sewage treatment practice. The situation is quite different in Great Britain, however, where the shortage of fats—and consequently of soap—has resulted in an enormously increased usage of synthetic detergents for both domestic and industrial purposes. Consumption of detergents is expected to continue at a high rate even when the soap shortage is over.

In February, 1948, the Northeastern Branch of the Institute of Sewage Purification conducted a symposium on "New Problems in Sewage Treatment with Special Reference to Synthetic Detergents." Papers were included on the types and characteristics of detergents in common use, their effects on the treatment of domestic sewage alone and of mixtures with wool scouring waste, and on possible methods of dealing with the problem. The studies reported were mostly of laboratory scale, but some interesting findings were disclosed.

Two types of synthetic detergents in general usage are described: one made from an aromatic petroleum residue resulting as a byproduct from oil refining, and the other a non-ionic ethylene oxide condensation product. The two compounds were found to cause somewhat different effects in the sewage treatment studies, particularly with respect to chemical precipitation.

Generally, the British workers suggest the following possible effects on sewage treatment processes as a result of the growing use of synthetic detergents:

1. The advantage to sedimentation will be lost of the flocculating effect of the curd that is precipitated in the reaction of soap with the hardness of the water supply.

2. Emulsions of grease or oil will be stabilized, reducing removal as sludge and scum at primary tanks and increasing loadings of secondary treatment processes.

3. Chemical precipitation is definitely affected; alumino-ferric and chlorinated copperas give good results but at high dosages.

4. The surface tension of the sewage is lowered, affecting the transfer of atmospheric oxygen in aerobic processes and creating a different biological environment.

5. There may be a tendency toward dispersal of activated sludge flocs.

6. Present methods of acid-cracking of wool scouring wastes are rendered erratic, temperature control appears

* *American City*, December, 1947, page 99; also March, 1948, page 111.

significant, and removals of wool grease are lowered.

Although they are not pointed out in the symposium referred to above, there may be some effects of synthetic detergents that will possibly be beneficial from the sewage treatment standpoint. For example, the free fatty acids in the sewage will be reduced to such extent as soap is replaced by the use of detergent products. Again, the formation of slimes in sewers and treatment structures, now believed to be largely responsible for hydrogen sulfide production, will be discouraged.

And so the changing times bring another problem of greater or less moment, to add complications to processes that are already complex. There is a hint of the potential degree of complication in the following statement by Goldethorpe and Nixon, who participated in the British symposium:

"These surface active agents in use are not generally destroyed nor do they form permanent chemical combinations in their application. Merely a loosely held physical association is made and only a sewage chemist's nightmare could give any idea of what is likely to happen to the flow of domestic sewage and trade waste as it comes tumbling down the sewers with nearly every organic solid dispersed, protected or solubilised. Mills some years ago found domestic sewage solids to have a colloidal content of merely 10 per cent. In the future is the work of the colloid chemist to overshadow the newly won glory of the biologist?"

There is not to our knowledge any current research in the United States on this subject. It is hoped that the matter will receive immediate and thorough study, so that we will be prepared to meet a situation such as exists in Great Britain today. Meanwhile, the plant operator will look askance at unusual foam accumulations in aeration tanks, while entertaining nostalgic thoughts of the days when his only concern was with such "simple" compounds as proteins, carbohydrates, lipids, skatoles, mercaptans, etc.

Oh "VEL_4" if the "BREEZE" causes a little "DREFT" perhaps the "TIDE" will turn!

NO SOONER SAID . . .

An editorial in the last issue of THIS JOURNAL referred to the possibility that a new profession embracing the sciences of biology, chemistry and engineering might find a place in the modern scheme. It was jocularly suggested that such "Biochemical Engineers" would be needed to moderate conflicting claims that might arise in any three-cornered debate on the relative importance of engineers, chemists and biologists in the sewage and industrial waste treatment field.

A note from Dr. M. Starr Nichols, Director of the Wisconsin State Laboratory of Hygiene, calls attention to the fact that the University of Wisconsin is offering a course and degree in Biochemical Engineering. It is hoped that some of these new specialists will find their way into our ranks.

W. H. W.

Proceedings of Member Associations

ARIZONA SEWAGE AND WATER WORKS ASSOCIATION

1947 Annual Meeting

Douglas, Arizona, April 11–12, 1947

The 1947 Annual Meeting of the Arizona Sewage and Water Works Association was held at Douglas, Arizona, April 11th and 12th, 1947, with 75 members and guests registered.

In welcoming the group, the mayor of Douglas reviewed the position that Douglas has grown to among the cities of Arizona. J. R. Denny, water superintendent, Douglas, traced the development of the host city and its water supply in his paper, "A Brief History of the Douglas Water Department." Other water supply topics presented and discussed were:

"Problems of Locating a Water Supply With a Low Fluorine Content," by C. T. Dickson, Arizona Edison Co., Inc., Coolidge, Ariz.

"Studies in the Measurement of Tuberculation, and an Index of Corrosion, and Anti-Corrosion Treatment Methods of Control," by Edwin W. Barbee, San Francisco (Calif.) Water Department.

"Publicity and Public Relations for Water Authorities," by Ray Goudy, Sanitary Engineer, Truesdail Laboratories, Los Angeles, Calif.

On the sewerage side, the topics discussed were interesting and varied. They included a paper by Richard Bennett, City Engineer's Office, Phoenix, on "Maximum Sewage Flow for Sewer Design;" a discussion of the "Application of Sulfur-Iron Salts to Irrigation Water," by Harmon E. Keyes, consulting chemist, Phoenix; an evaluation of the use of cone valves, by Harold W. Yost, consulting engineer, Phoenix; an explanation of the use of Cloroben in sewage treatment, with particular reference to experiences at Long Beach and Los Angeles, Calif., by J. L. Todd and J. L. Leggett, Los Angeles Chemical Company; and a paper by John A. Ladlow, Chicago Pump Company, Phoenix, on experiences with small sewage treatment plants.

The meeting was concluded with an inspection trip to the recently constructed sewage treatment works built by the International Boundary Commission to serve Douglas, Ariz. and Aqua Prieta in Sonora, Mexico.

Officers elected for 1947–48 were:

President: Harold W. Yost, Phoenix, Ariz.
First Vice President: John Rauscher, Tuscon, Ariz.
Second Vice President: R. R. Ribal, Oakland, Calif.
Secretary-Treasurer: George W. Marx, Phoenix, Ariz.

GEORGE W. MARX,
Secretary-Treasurer

GEORGIA WATER AND SEWAGE ASSOCIATION

Sixteenth Annual Meeting

Atlanta, Ga., September 17–19, 1947

The Sixteenth Annual Meeting of the Georgia Water and Sewage Works Association was held at the Georgia School of Technology, Atlanta, Ga., on Sept. 17–19, 1947. The meeting, co-sponsored by the Association, the Georgia Department of Public Health, and the college, was attended by more than 300 registrants.

Col. Blake R. Van Leer, president of Georgia Tech., welcomed the group and described the expansion of the graduate school facilities of the college. A master's degree in sanitary engineering is now being offered and a Technical Institute is being established for the training of technologists or technicians for varied industries.

The first speaker on the first technical session of the program was Francis S. Friel, president of the Federation, who spoke on "Responsibilities of Water and Sewage Plant Operators." In expanding the basic concepts of responsibility, Mr. Friel discussed the operator's relationship to his job, his employer, and to himself. The value of a good public relations program in carrying out operator responsibilities was emphasized. In closing, as president of the Federation Mr. Friel presented the Federation's Kenneth Allen Award for the Georgia Water and Sewage Works Association to Gilbert Frith, of the Georgia Dept. of Public Health.

Sumter Kelley, attorney, of Atlanta, in discussing the topic "Financing Water and Sewage Facilities" explained the laws which govern Revenue Certificate Financing in Georgia.

Lecturing on the coagulation of water, Dr. A. P. Black, Professor of Chemistry, University of Florida, defined coagulation and explained the reactions involved in the precipitation of colloids. Other water works topics presented were:

"Elevated Tank Maintenance," by Charles J. Leary, president of the Leary Construction Co., Atlanta; "Pump Maintenance and Operation," by Professor Thomas M. Lowe, Director, Dept. of Civil Engineering, Alabama Polytechnic Institute, Auburn, Ala.; and "Corrosion Control," by Dr. A. P. Black.

George E. Symons, associate editor, *Water and Sewage Works,* in presenting the paper "Sewage Treatment Processes and Their Results" observed that there are only three processes of sewage treatment—primary treatment, secondary treatment, and disinfection, and that sludge disposal is a byproduct process of the first two.

The following papers concerning sewage works were also presented and discussed: "Chlorination of Water and Sewage," by Harry A. Faber, Research Chemist of the Chlorine Institute, Inc., New York City; "Sewer Construction and Inspection," by J. H. Bauer, engineer of Robert and Co., of Atlanta; "Sewage Sludge Digestion," by Ralph E. Fuhrman, superintendent, Dist. of Columbia sewage treatment plants, Washington, D. C.; "Sewage Treatment at Thomasville, Ga.," by M. B. Price, superintendent of sewage treatment, Thomasville, Ga.; "Practical Sewage Plant Operation," by G. R. Frith, engineer, Georgia Dept. of Public Health.

The symposium on the "Procurement of Water in Georgia" provided practical and timely information on the water obtainable from surface and underground sources.

Comer Turley, president of the association and mechanical superintendent of the Pepperell Mfg. Co., Lindale, Ga.,

presided at the annual banquet which was given with the compliments of the Southern States Chemical Co., of Atlanta.

Two annual awards were presented at the banquet. The Frederick J. McMullin Memorial Award for outstanding water plant operation was presented to W. C. Hartman, Milledgeville, Ga., and the William A. Hansell Memorial Award for sewage works operation was presented to M. B. Price, Thomasville, Ga.

Following the banquet and presentation of awards, George E. Symons spoke on "How Are Your Relations—Public, That Is!"

New officers of the association elected for the year 1947–48 are:

President: B. L. Coburn, Fitzgerald, Ga.
First Vice President: D. H. Hurst, Tifton, Ga.
Second Vice President: Clyde Angle, Rome, Ga.
Secretary-Treasurer: Van P. Enloe, Atlanta, Ga.

VAN P. ENLOE,
Secretary-Treasurer

NORTH CAROLINA SEWAGE WORKS ASSOCIATION

27th Annual Meeting

Greensboro, North Carolina, November 10–12, 1947

The 27th Annual Joint Conference of the North Carolina Sewage Works Association and the North Carolina Section of the American Water Works Association was held at the Sedgefield Inn, Greensboro, N. C., on November 10–12, 1947. A total of 212 members and guests were present.

The meeting was called to order by J. A. English, Section Chairman, who appointed the necessary convention committees. Honorable Fielding L. Fry, Mayor of Greensboro, cordially welcomed the group to Greensboro.

The technical program was opened by Dr. Zachary M. Stadt, Dental Officer, City Health Department, Charlotte, N. C., who discussed the subject "The Dental Viewpoint of the Application of Fluorine to Water." A lively and stimulating discussion period followed.

The afternoon session was devoted to roundtable discussions of water works problems.

The social highlight of the meeting was the buffet supper and entertainment provided the group through the courtesy of the Pomona Terra Cotta Company, of Greensboro.

The annual business meeting of the section opened the November 11th session. The following officers were elected to serve during 1947–48:

Chairman: W. W. Franklin, Charlotte
Vice Chairman: R. W. Luther, Elizabeth City
Secretary-Treasurer: George S. Moore, Albemarle

The remainder of the session was devoted to the following papers and discussions: "Sludge Digestion," by Harry E. Schlenz, Pacific Flush-Tank Company, and "Discussion of High-Rate Trickling Filters," by Robert C. Gloppen, Yoemans Brothers Company.

Linn H. Enslow, Vice President, and W. W. Brush, Treasurer of the American Water Works Association, were guests at the Honorary Luncheon for national officers and guests. Mr. Brush brought greetings to the group and Mr. Enslow addressed the meeting, using as his subject "Going Forward with the American Water Works Association." George S. Rawlins, North Carolina Director of the Federation, read an address prepared by President George S. Russell, of the Federation.

The afternoon provided opportunity for roundtable discussions on the following sewage works problems: "Sewer System Maintenance," D. M. Williams, Durham, leader, and "Sewage Plant Operation," R. S. Phillips, Charlotte, leader.

The annual banquet and dance of the two associations featured presentations of the annual awards. Thad C. Burnett, Asheville, was presented the Maffitt Membership Cup for having obtained the most new members for the North Carolina Section of the American Water Works Association for the year. The Ludlow Cup for new members obtained for the North Carolina Sewage Works Association was awarded to E. L. Nance, of Charlotte. Following presentation of the George Warren Fuller award to John R. Purser, Jr., of Charlotte, Waldo G. Bowman, editor, *Engineering News-Record*, addressed the group. The dance following the banquet was enjoyed by all.

The November 12th morning session technical papers were as follows:

"Selection and Care of Water Meters," by Charles Bachman, New York, N. Y.

"The Pittsburgh Erie Method of Coating Water Pipe in Place," by A. B. Anderson, Pittsburgh, Pa.

"Development and Application of the Centriline Process of Cement Lining Water Mains in Place," by K. K. Kerwain, Jr.

All of these papers presented valuable information and were interestingly discussed. The meeting was adjourned immediately after the technical session to meet again Nov. 8–10, 1948, the place of the meeting to be selected.

GEO. S. MOORE,
Secretary-Treasurer

VIRGINIA INDUSTRIAL WASTES AND SEWAGE WORKS ASSOCIATION

First Annual Meeting

Ocean View (Norfolk), Virginia

First Annual Meeting of the Virginia Industrial Wastes and Sewage Works Association was held Thursday and Friday, Oct. 16–17, 1947 at Hotel Nansemond, Ocean View (Norfolk), Virginia. Ninety-three persons were registered, including members and guests.

Following the call to order and the appointment of committees by President Digges, a short business session was held. The group then reassembled for luncheon, which was highlighted by showing the General Electric film, "Clean Waters."

General topic for the Thursday afternoon session was "Industrial Wastes." Subjects were chosen to cover those trade wastes of principal interest to Virginians. Papers presented were:

"Oxygen Balances of a Swamp Stream," by Stuart Crawford, research chemist, Camp Manufacturing Co., Franklin, Virginia. Discussion was led by E. J. Axe, engineer, North Carolina Stream Sanitation and Conservation Committee, Raleigh, North Carolina.

"Preventing Stream Pollution from Vegetable and Fruit Canning Wastes," by N. H. Sanborn, National Canners' Association, Washington, D. C.

"Pigs Minus Saleable Meat Equals Blood, Scum, Hair, Grease, Dirt and Manure—What Are We Going to do about Them?" by G. R. Frith, public health engineer, Georgia State Department of Health, Atlanta, Georgia.

"The Rayon Manufacturing Waste Problem—Can It be Solved?"

a. "Viscose Rayon Wastes," by

E. T. Roetman, sanitary engineer, American Viscose Corporation, Philadelphia, Pennsylvania.

b. "Acetate Rayon Wastes," by Roy McCracken, assistant technical superintendent, E. I. duPont de Nemours & Co., Inc., Waynesboro, Virginia.

The annual banquet Thursday night was attended by 102 persons. J. C. Biggins, chairman, Hampton Roads Sanitation District Commission, Norfolk, welcomed the Association to the Hampton Roads area. For the principal part of his address, he outlined the historical and technical details incidental to establishing the commission and its efforts to provide sewage treatment for the communities of the area. President Digges responded to the address of welcome for the Association, Bryant W. Strother for industry, and Richard Messer for the sewage men.

Sessions Friday were devoted to sewage disposal. The only paper was presented by J. Kenneth Bailey, sanitary engineer, Langley Field, Virginia, who spoke on "Trickling Filters and Their Operation." Following this, the group was taken on an inspection tour of the Hampton Roads Sanitation District Commission's Army Base sewage treatment plant, which had started operating only the night before.

At the business session it was voted unanimously to adopt the nominating committee's report recommending that officers elected at the March 4, 1947 organization meeting be retained for the next year. These are:

President: Reid W. Digges, Norfolk
Vice President: Bryant W. Strother, Richmond
Secretary-Treasurer: A. H. Paessler, Richmond
FSWA Director: L. L. Hedgepeth, Richmond

A. H. Paessler,
Secretary-Treasurer

MEMBER ASSOCIATION MEETINGS

Association	*Place*	*Time*
New York State Sewage Works Association	Hotel Niagara, Niagara Falls, N. Y.	June 4–5, 1948
Florida Sewage Works Association	University of Florida, Gainesville, Fla.	June 7–12, 1948
Central States Sewage Works Association	Hotel Schroeder, Milwaukee, Wis.	June 18–19, 1948
Ohio Conference on Sewage Treatment	Dayton-Biltmore Hotel, Dayton, Ohio	June 23–25, 1948
Kentucky-Tennessee Industrial Wastes and Sewage Works Assn.	Chattanooga, Tenn.	Aug. 23–25, 1948
Pennsylvania Sewage Works Association	Nittany Lion Inn, State College, Penn.	Aug. 25–27, 1948
Iowa Sewage Works Association	Hotel Kirkwood, Des Moines, Iowa	Sept. 14–15, 1948
Rocky Mountain Sewage Works Association	Plains Hotel, Cheyenne, Wyo.	Sept. 15, 1948
Georgia Sewage Works Association	Georgia Institute of Technology, Atlanta, Georgia	Sept. 22–24, 1948
West Virginia Sewage and Industrial Wastes Association	Stonewall Jackson Hotel, Clarksburg, Va.	Sept. 30–Oct. 2, 1948
Arizona Fall Conference	Phoenix, Ariz.	Oct. 15–16, 1948
Federation of Sewage Works Associations	**Statler Hotel, Detroit, Mich.**	**Oct. 18–21, 1948**
Michigan Sewage Works Association	Statler Hotel, Detroit, Mich.	Oct. 18–21, 1948
North Carolina Sewage Works Association	George Vanderbilt Hotel, Ashville, N. Carolina	Nov. 8–10, 1948

Reviews and Abstracts*

Further Experiments on Nitrification and Recirculation in Percolating Filters.† By James H. Edmondson and S. R. Goodrich. *Institute of Sewage Purification,* 9 pp. (Dec. 3, 1947).

This paper reports further experiments by the authors. The original work was published in the *Journal of the Institute of Sewage Purification* in 1943.

The effect of applying a nitrated effluent to a "ponding" trickling filter was investigated and it was found that the application of nitrated effluent causes the accumulations of grey film to disintegrate rapidly, leaving the filter medium in a clean and healthy condition. This method has been extensively used for cleaning up various filters used in these experiments.

The possibility of treating primary tank effluent at a high rate on trickling filters previously matured as nitrifying filters was investigated in 1944. An experimental unit was operated as a nitrifying filter for about 3 months, in which time nitrification was well established. The feed was then changed to primary tank effluent which was applied at the rate of 400 gal. per cu. yd. per day for 6 days each week. On the seventh day it was dosed with nitrated plant effluent. The experiment lasted 8 months. The filter effluent was consistently of good quality and high nitrification was maintained throughout the period of experiment. The discontinuance of the experiment was influenced by excessive odor from the surface of the filter.

In the original paper it was noted that when a trickling filter is dosed with sewage diluted with nitrated effluent, denitrification took place in the top 30 in. of the filter, and that this was followed by a nitrifying zone which reached a maximum at a depth of about 5 feet. These results have been confirmed.

A small scale experiment was carried out on recirculation with particular attention to nitrification. A matured filter was dosed with a mixture of equal parts of sewage and its own effluent at the rate of 600 gal. per cu. yd. per day. One day per week the filter was dosed with nitrated effluent alone. From the beginning the filter produced a well-nitrified effluent.

Experiments were also conducted on the most suitable type of medium for filters of this type. These investigations indicated that material retained on a 1 in. but passing a 2-in. circular mesh screen is suitable provided it is contained in 80 per cent of the depth. Also, it was shown that a 6-ft. depth filter gave results similar to those obtained from an 8-ft. filter.

Large scale experiments along similar lines were conducted at two sewage treatment plants.

Experimental results reported indicate the value of establishing high nitrification in high-rate trickling filters prior to normal operation and the resistance of nitrification when firmly established. The large scale experiments indicated substantial reserve capacity in normal trickling filters of good design. In one instance it was shown that a recirculating filter was capable of treating the same volume of sewage that was formerly applied to three normal filters of similar size. Five references are given.

Paul D. Haney

Some Future Problems in Sewage Purification at Bradford.‡ By C. C. Beedham. *Institute of Sewage Purification,* 9 pp. (Nov. 8, 1947).

Since its construction in 1926 the Esholt Works of the city of Bradford has become, in effect, a regional sewage treatment plant

† A preprint.

‡ A preprint.

* Please send to Federation headquarters all periodicals, bulletins, special reports, etc., which might be suitable for abstracting in This Journal. Publications of public health departments, stream pollution control agencies, research organizations, and educational institutions are particularly desired. Address such material: Federation of Sewage Works Assns., 325 Illinois Bldg., Champaign, Ill.

for a large part of the Aire River valley. The Esholt plant was designed to treat a particularly difficult sewage containing wool scouring wastes, and the settling tanks and biological filters were built of ample capacity. However, as the area served by this plant increased and the load became heavier it was necessary to study the plant carefully with a view to maintaining plant efficiency without extensive new construction. This paper presents the measures adopted and research undertaken to achieve the end of efficient treatment.

Briefly, the measures adopted have included a program for the gradual reconstruction of the biological filters, and a plan for balancing the daily flow and securing continuous working of the filter beds. Research has included a study of an experimental rapid filtration unit and experiments on recirculation.

The sewage treated at the Esholt Works is roughly 50 per cent domestic sewage and 50 per cent industrial waste from the wool-scouring and dyeing industries. The wool-scouring waste causes the most difficulty. In its raw state this waste is an emulsified liquor with a high oxygen demand. Some of this waste is pretreated at the factory by means of acid which breaks the emulsion thus allowing grease recovery. None of the industries practice flow equalization.

The best method of treating the highly colloidal sewage received at the Esholt Works is to adjust the pH of the sewage to 3.5 with sulfuric acid prior to sedimentation. This results in the satisfactory removal of solids, and the sludge can be kept for about 3 months in the settling tanks without anaerobic decomposition. Grease recovered has a high value and the revenue largely offsets the total costs of the works. However, the settling tank effluent (pH = 3.5) is quite corrosive and difficult to treat biologically. Adjustment of pH with soda ash was found to be prohibitively expensive. The best solution was found to be use of the acid only when substantial quantities of wool scouring wastes were being received at the plant.

It is noted that another problem that may become serious in the future is that resulting from the use of various synthetic detergents by the textile industry. Textile wastes containing these detergents are not amenable to acid precipitation.

The existing trickling filters have an area of 53.5 acres and the filter media is coal. Distribution is accomplished by travelling distributors operated by ropes. Power is provided by tank effluent flowing over water wheels. It is planned to reconstruct these filters substituting broken sandstone for the coal. The coal will be salvaged. The new media will be graded as follows: bottom course, 4 to 6 in.; middle course 2 to 3 in.; top course 1 to 1.5 in.

Experiments on recirculation from the secondary settling tanks to one of the filters indicated that such recirculation improved plant performance. The one disadvantage would be the cost of pumping.

The process of high rate trickling filtration was studied by means of specially constructed units. Primary tank effluent was fed to a high rate filter at the rate of 1,000 gal. per cu. yd. of media per day. The media consisted of 3-in. sandstone cubes and was 9 ft. deep. Effluent from this filter discharged to a humus tank which was followed by a "normal" filter, having a media (coal) depth of 5 ft., 6 in., and a second humus tank. The "normal" filter was operated at a rate of 140 gal. per cu. yd. per day, excess effluent from the first filter being discarded. The B.O.D. reduction by the first (high rate) filter and clarifier was about 25 per cent. The sludge from this filter was not nearly so gelatinous as ordinary trickling filter humus. The water content was about 95 per cent. The proportion of grease was similar to that in the primary sludge (35–40 per cent). It was concluded that by treating part of the raw sewage with acid and passing the remainder through a high-rate filter it would be possible to recover practically all of the grease. It was found by experiment that precipitation of 75 per cent of the sewage with acid followed by mixing with the remaining 25 per cent produced a mixture having a pH satisfactory for subsequent treatment.

Eight references and three figures are included.

PAUL D. HANEY

Damage to a Birmingham Sewer by Sulphation. BY D. G. BEVAN. *The Surveyor,* 106, 621–622 (Nov. 28, 1947).

Certain sewers in the Sheldon area of the Birmingham District have been seriously damaged by the action of sulfates in

the ground water. The sewers were built under an unemployment relief project and were completed in 1934. They were built under the direction of first-class engineering contractors, and the work was adequately supervised.

In 1938 inspection showed defects on a 21-in. branch sewer. The joints in the brickwork in the manholes were softening and were commencing to leak. A soft white deposit appeared on the walls. Joints in the sewer pipe showed similar defects. At the time, the joints were pointed and the pipe cleared of incrustations as much as possible. Due to the war nothing more was done for 6 years.

In 1944, after bomb damaged sewers were repaired, routine inspections of sewers were resumed. It was found that serious deterioration had taken place in the joints in the manholes and the stoneware sewers, and in large brick and concrete sewers. Ground water was entering the sewers in large quantities. Excavations were made in order to examine the outside of the brick and concrete sewers. Some of the concrete was found to be so weak it could be broken up by hand. Disintegration was most severe at the construction joints at the spring line.

Samples of ground water were collected and analyzed. Results showed concentrations of sulfates varying from 390 to 1,460 p.p.m. in seven samples. As a rough guide to the risk to damage to concrete, the following may be used.

Range in Concentration of Sulfates	Action to be Expected
Up to 300 p.p.m.	None, or slow action only
300 to 1,000 p.p.m.	Moderately severe
Above 1,000 p.p.m.	Rapid action likely

T. L. HERRICK

Sewage Purification Questions. The Present Position; Control of Nuisances; Utilization of Products; Professional Training. BY F. T. HAMBLETON. *The Surveyor,* **106**, 649–650 (Dec. 12, 1947).

In recent years valuable research has been carried on and many technical advances have been made in sewage treatment. However, little practical use has been made of these discoveries as sewage disposal construction has been at a standstill. At present many plants are badly in need of reconstruction or extensions.

The production of an effluent of good quality is of prime importance, but if other considerations are neglected the works superintendent may not be doing a complete job. If the plant is a health hazard and detracts from the pleasure of living for people in the vicinity, it is not wholly successful. Both conditions are at hand if flies and odors are permitted. Control of fly and odor nuisance is becoming more and more important as towns are built closer to the treatment works.

There have always been those who claimed a profit could be realized in the utilization of sewage products, and the most usual method suggested for realizing this has been use in agriculture. Application of liquid or solids or both has been advocated. Regardless of how much the advocates of sewage farms were criticized or ridiculed, it must be remembered that there were occasionally some sewage farms which produced good effluents and showed an actual profit.

More information is needed on the use of sewage sludge for agricultural purposes. More use might be made of effluents in agriculture. Remarkable results have been obtained in South Africa, and while the climate there is vastly different than that of England, irrigation with effluents at proper times might work wonders for the farmer.

Utilization of sludge gas as a fuel has become a matter of national duty now that fuels are scarce. It has been reported that reasonably dry sewage sludge can be used as a boiler fuel.

The manufacture of chemicals and plastics is another use of gas from sludge digestion. Some processes are already workable on a commercial scale. At the International Chemical Congress held in London last summer Dr. H. Levinstein said, "We may return from coal and oil as a source of raw materials to plant and organic life by the exploitation of sewage. The methane and ammonia could be made to make nylon." He also said that "The neglect of town sewage is a shocking waste."

The extraction and sale of grease from textile sewages has been another phase of

byproduct recovery. At one plant the recovered grease is processed at the works and the refined products marketed.

T. L. HERRICK

Prevention of Pollution by Oil from Engineering Factories. By C. HOGG, A. E. J. PETTET, AND W. F. COLLETT. *The Surveyor*, **106**, 555 (Oct. 24, 1947).

Serious pollution of streams and difficulties at sewage works occurred from the discharge of oily wastes from various manufacturing plants in England during the war. The Water Pollution Research Laboratory, at the request of the Ministry of Aircraft Production, investigated methods for preventing the pollution.

Cutting oils used in the production of aircraft engines may be either neat mineral, animal, or vegetable oils, or aqueous emulsions containing soluble oils. The neat oils are collected and sold to refiners, but the collection is rarely complete. The emulsified oils are generally discharged to sewers. Floor washings represent a source of considerable oil, and in the factory at which this study was made the floors were degreased with caustic soda, soda ash, and a proprietary detergent known as Gunk, containing soft soap, crude xylene, and chlorinated hydrocarbons.

In the laboratory investigation, samples of spent emulsified cutting oils were treated with varying proportions of solutions of aluminum sulfate, aluminoferric, ferric chloride, calcium chloride, sodium chloride, sulfuric acid, and calcium hydroxide. Oxygen consumption by permanganate (N/80 for 4 hr. at 26.7° C.) was then determined on the aqueous layer. It was noted that with aluminum sulfate and ferric chloride a sharp drop in oxygen absorption occurred at a certain dose of reagent, and at that point the emulsions were abruptly and completely broken. This sharp change did not occur with the other reagents. Calcium hydroxide, at concentrations up to 2,000 p.p.m., was effective in breaking emulsions, but the oil separated in a slight, bulky form difficult to remove from the aqueous layer. Calcium chloride and sulfuric acid were effective in breaking emulsions containing 2 per cent oil, but were less so with weaker emulsions. Hydrochloric acid and bleaching powder were ineffective. Experiments on a larger scale (40-gal. batches) gave similar results.

Aluminum sulfate was selected for further work on floor washings. Experiments similar to those made on cutting oil emulsions showed that 1,950 p.p.m. of this compound effectively clarified the aqueous layer, but the oil layer was light and floeculent. It was found that a compact oil layer could be formed if the washings were first made distinctly acid with sulfuric acid. Another series of experiments showed that any proportionate combination of cutting oil emulsion and floor washings could be treated successfully with hydrated aluminum sulfate and sulfuric acid.

A commercial plant was built on the basis of these experimental findings. A sewer was constructed of 6-in. vitrified clay to carry the oily waste from the various shops to the treatment plant. Separation of free oil was effected in four tanks in parallel, each 20 by 5 by 2 feet deep. The waste water was admitted to the tanks direct from the sewer, and the level in the tanks was adjusted to permit separated oil to flow over a weir to a launder discharging to a storage sump. The aqueous layer flowed from the bottom of the tanks to a second weir chamber whose weir-plate was set about ½ in. below the level of the oil weir. The aqueous layer flowed to a wet well for storage. Continuous-flow operation proved satisfactory, with the two layers discharging simultaneously.

The plant for treating the emulsion consisted of four 1,100-gal. tanks about 6 ft. sq., with pyramidal bottoms. Each tank had an inlet line, scum outlet channel, decanting valve 4 ft. below top water level, and sludge valve. Service pipes delivered 30 per cent sulfuric acid, aluminum sulfate solution, tap water, and compressed air to each tank. Spent plating shop acid was used in place of sulfuric acid whenever available.

A one-month trial run was made when the plant was put in service. Storage was adequate to allow the waste from 24-hr. operation to be treated during the day shift, and about 3,000 gal. per day was treated in the trial period. Treatment tanks were filled from the wet well, and

the liquor was mixed with compressed air before taking a sample for titration. Acid for neutralization was calculated from the titration. A standard dose of 12 lb. of aluminum sulfate in 6 gal. of water, plus enough sulfuric acid to make the charge definitely acid, was then added. Trials disclosed that 9 lb. of acid, as H_2SO_4, in excess of that required for neutralization, gave good results. The tank contents were thoroughly mixed with compressed air and allowed to settle for 4 hours. The scum was then skimmed off to scum channels, and the clear liquor drawn off through the decanting valve. The 300 gal. remaining below the decanting valve level was made a part of the next charge by adding 800 gal. of emulsion and proceeding with the treatment as outlined. The aqueous layer was treated in the lime-dosing plant at the plating shop to reduce its acidity. The scum (120 gal. per day) was burned in the plant incinerator. The following table gives the results of some trial runs.

Composition (% by vol.)			Acid (p.p.m.)		Oxygen Consumed (p.p.m.)			Oil in Emulsion (per cent)		
Residues	Floor Washing	Shop Waste	To Neut.	Excess	Untreated	Treated	% Red.	Untreated	Treated	Red.
0	0	100	1,100	1,500	1,590	770	52	0.27	0.007	97
0	0	100	500	1,000	1,240	680	45	0.30	0.063	79
0	50	50	750	1,200	1,560	550	65	0.38	0.056	85
0	75	25	580	1,500	1,710	830	51	0.29	0.033	89
0	100	0	650	750	1,360	820	40	0.41	0.065	84
0	100	0	1,650	750	1,430	670	53	0.18	0.014	92
0	100	0	250	750	770	430	47	0.09	0.017	81
25	75	0	500	500	1,170	700	40	0.16	0.030	81
25	75	0	330	900	1,240	610	51	0.41	0.033	92

During an 11-month period, an average of 73,320 gal. of waste was treated per month, and 2,440 gal. of oil was recovered which was sold for about $80. Monthly chemical consumption averaged 620 lb. aluminum sulfate and 63 gal. concentrated sulfuric acid. The net operating cost was $278 per month. Total cost of plant and oil collection system was $60,000.

The treatment plant corrected the problem of disposing of oil waste from the shops, but the problem of pollution from accidental spills and drippings from engines in transit, remained. The drainage area of the plant contained 41 acres of equivalent unpermeable area. An additional plant was designed for a maximum rainfall of 20 cusecs, or approximately ½ in. per hour, to separate oil from the surface run-off. Two interceptor tanks, 60 by 12 by 3½ ft., were built as a unit to operate in parallel. Surface drainage was diverted to the tanks and controlled by a penstock. Water level in the tanks was controlled by the outlet weir.

Each tank was equipped with three equidistant timber baffles dipping 1¾ ft. below the level of the outlet weir. Floating oil retained by them was removed by a floating boom discharging to a sump. Water separating from the skimmed oil was discharged from the bottom of the sump, and the oil was sold to refiners. The cost of the tanks, flumes and equipment was $23,200.

This combination of chemical treatment and drainage interceptors was successful in eliminating pollution at the plant where it was installed. It is pointed out that oil removal must be quite effective, because oil is visible on water in a layer about 0.000012 in. thick, corresponding to the dispersion of one gallon of oil over a water surface of 4 acres.

There are six tables of data, one graph, one working plan, and three photographs of the treatment plants.

RICHARD D. HOAK

Loss of Sanitary Sewage Through Storm-Water Overflows. BY J. E. MCKEE. *Journal, Boston Society of Engineers,* **34**, 5–92 (April 1947).

In the design of intercepting sewers connected to combined sewerage systems, engi-

neers endeavor to determine how much storm-water runoff will be intercepted; what proportion of sewage, diluted by storm water, will overflow, and the frequency of overflow. But little data are available, based on actual observations or an analysis of the problem, probably because of the difficulty of collecting data where a number of sewer outlets may be involved.

In analyzing the problem under rainfall conditions at Boston, Mass., using statistics for the years 1934 to 1945 inclusive, McKee found that rainfall equal to or in excess of 0.01 in. per hr. occurred 6.64 per cent of the total time, whereas precipitation recorded as a trace or more occurred 14.9 per cent of the total time. He shows that storm runoff equal to the dry weather sanitary flow (abbreviated hereafter as d.w.f.) is produced by a rainfall of 0.01 in. per hr., after impervious surfaces are well wetted. When twice the average d.w.f. is intercepted, about 2.7 per cent of all the domestic sewage may escape, or 97.3 per cent of all sewage will be intercepted during the months of June through November.

If the interceptor is designed to take 5 times the d.w.f. (*i.e.,* 0.04 in. per hr. of storm water), the percentage of sanitary sewage escaping can be reduced to 1.2 per cent. The frequency of overflow with twice the d.w.f. intercepted is about 5 to 6 times per month in the summer. With 10 times the d.w.f. intercepted, the number of overflows may be reduced to three per month, and the sewage overflowing is reduced to 0.6 per cent.

The author discusses in detail the rainfall probability in Boston; the runoff from low-intensity rainfall, indicating that rainfalls of 0.20 in. per hr. or more constitute only 10 per cent of the total hours of rainfall, whereas 90 per cent of all the hours of rainfall have less than 0.20 in. per hr.; the relation between dry-weather flow and the run-off from low-intensity rainfall; the duration and extent of sewage overflows; the frequency of sewage overflows.

McKee concludes that the peak d.w.f. in most combined sewers ranges from 1.5 to 3 times the average d.w.f., and that if interceptors are designed to carry the peak d.w.f., sanitary sewage mixed with storm-water may overflow about 5 or 6 times per month. If the interceptors have a capacity of 10 times the d.w.f., the number of overflows is reduced to about three per month. Thus by increasing the capacity of the interceptors approximately five-fold, the number of overflows per month is only halved. The added cost of the larger interceptors does not appear to be justified by the reduction in number of overflows.

In the discussion, W. E. Stanley cites data from Chicago, Minneapolis-St. Paul, and T. A. Berrigan notes the conditions in the Boston metropolitan sewerage system.

LANGDON PEARSE

Treatment and Disposal of Sewage and Waste Waters from Shell-Filling Factories. By R. W. WILKINSON. *Institute of Sewage Purification Journal and Proceedings,* Part I, pp. 145–150, 1945.

The sources of waste from a shell-filling factory are (1) from laundries in which protective clothing contaminated with explosives are washed, (2) from the washing of tools, floors, etc., and (3) from washing out of rejected ammunition. Washing of contaminated clothes entails special and sometimes severe methods to remove trinitrotoluene, ammonium nitrate and "tetryl." Rectification or cleaning out of defective ammunition is an important source of waste containing trinitrotoluene and ammonium nitrate. The former chemical being sparingly soluble in water, most of it is removed by sedimentation. The volume of waste arising from the laundry is 1.5 gal. (Imp.) per employee per day, on the basis of all the workers in the factory. The highest B.O.D. in the waste from the laundry came from washing the clothing in hot soap solution, and the highest trinitrotoluene was derived from the "breakdown" processes in the laundry. The average laundry waste had a B.O.D. of 180 p.p.m. and trinitrotoluene of 11 p.p.m.

The volume of waste derived from washing of tools and floors and rectification of defective ammunition was estimated to be 0.5 per cent of the total volume of sewage and waste. The total volume of sewage and waste varied from 9 to 16 gal. (Imp.) per employee per day. The average B.O.D. from all types of factories varied 155 to 278 p.p.m. The highest pH value

was 8.6 and the lowest 7.3. Usually the mixed liquid was yellowish.

Since the sanitary sewage in most factories was treated by trickling filters the effect of the addition of "contaminated" laundry waste to domestic sewage was investigated experimentally. Synthetic "contaminated'' laundry waste with higher concentrations of the various ingredients was added to sewage in various volumetric ratios. The results indicate that there will be no difficulty in treating by biological filtration the mixed liquors from a shell-filling factory at which the volume of domestic sewage to laundry waste is as low as 4 to 1. The ratio in factories was usually from 6 to 1 to 10 to 1.

The possible inhibitory action of trinitrotoluene on bacteria was investigated and it was found that in domestic sewage 40 p.p.m. had no effect.

The mixed sanitary sewage and waste from factory were treated on large scale by sedimentation and trickling filters. These filters had previously treated domestic sewage at the rate of 135 gal. (Imp.) per cu. yd. per day for about 12.5 hours each day. The rate of application of mixed sanitary sewage and waste from the factory was increased from 63 to 90 gal. (Imp.) per cu. yd. per day. The B.O.D. of the settled effluent from the filters increased from 3.5 p.p.m. at the lower rate of application to 15 p.p.m. at the higher rate. It was concluded that waste waters from shell-filling factories could be treated satisfactorily when mixed with the sanitary sewage from the premises.

The addition of 30 p.p.m. of trinitrotoluene to sewage had no effect on the rate of digestion of the sludge derived from it. Even with 60 p.p.m. of trinitrotoluene added to sewage the sludge digested almost as readily as with no addition.

H. HEUKELEKIAN

Report of the Joint Board Established to Investigate and Study and to Prepare Plans and Maps for the Disposal of Sewage in the Merrimack River Valley. (Commonwealth of Massachusetts, Senate No. 550.) BY T. R. CAMP, 404 pp. (1947).

Under Chapter 62, Resolves of 1945, of the Commonwealth of Massachusetts, a Joint Board investigated the disposal of sewage in the Merrimack River Valley in Massachusetts. The report of T. R. Camp describes in detail the pollution of the Merrimack River by Lowell and Lawrence and surrounding territory, of which 77.5 per cent of the B.O.D. is due to industrial wastes.

Regional treatment in four main projects is recommended, with activated sludge treatment at Lowell and Lawrence, and sedimentation at Haverhill and Newburyport Harbor, all effluents to be chlorinated.

The cost of construction is estimated at $27,581,100. The annual cost is estimated $1,339,020, of which 58 per cent may be assessed to industry. Sixty-one per cent of the cost is attributable to volume, 15.4 per cent to B.O.D., and 23.4 per cent to suspended solids. Camp recommends that the costs be assessed on these bases by the proposed District staff.

The river has a total drainage area of 5,006 sq. mi., of which 3,798 sq. mi. are in New Hampshire. Low flows at Lowell may be expected under 700 c.f.s. for 1 per cent of the time, and less than 1,500 c.f.s. for 10 per cent of the time. The entire district has an equivalent population of 1,271,985 (as of 1947). The state census in 1945 showed 343,316 resident population (estimated in 1947 at 374,010).

The sewage flows were estimated from gagings and water consumption at the following gal. per cap. per day: Lowell, 60; Lawrence and Methuen, 70; Haverhill, 90; Amesbury, 65; Newburyport, 70; and Andover, 102.

An unusual feature of the report is an analysis of the effects of the discharge of sanitary sewage through storm-water overflows. With an interceptor designed for twice the dry weather flow, 50 per cent of the sewage will overflow during a storm of 0.03 in. per hr.; 82 per cent at 0.10 in. per hr.; and 96 per cent at 0.50 in. per hr. The report advocates interceptors for the peak dry weather flow with a small margin of safety against overflows in dry weather and separation of sanitary sewers from storm drains.

In the Lowell and Lawrence sewage works, the pH varies from 8.5 to 10.5. The use of CO_2 is proposed to adjust this to pH 8.0. Flocculation tanks and grease separators are provided in all the sewage treatment works.

All primary settling tanks will be long and narrow (length at least ten times width) with 5-ft. water depth, with detention periods of 1.1 hr. for average flow. An aeration period of 6 hr. is proposed, except for 8 hr. at Lawrence.

Heated sludge digestion tanks, with elutriation and vacuum filters, are proposed for the larger plants. Because of various local difficulties and objections, barging liquid sludge to sea was not recommended. Hauling sludge cake and dumping is believed more economical than incineration.

LANGDON PEARSE

Sanitary Service Charges in Tennessee —1947. PREPARED BY CHARLES L. CRANGLE. Tennessee State Planning Commission, Publication No. 183, Jan. 1948. (Price $1.00.)

This publication discusses the questions, "What is a valid water rate?", "How can sewer charges be apportioned?", "What charge should be made for garbage collection service?", and it presents tabulations of data pertaining to these questions obtained from Tennessee communities.

Information obtained from 92 of the 115 communities having public sewer systems disclosed that only 56 provided treatment of sewage and but 10 had complete treatment plants.

Of the 92 communities surveyed, only 34 (37 per cent) reported a sewer charge of any kind, and 8 of these made only a connection charge, with one town charging a $50.00 connection fee and a service charge of $1.00 per month for residences outside the city limits only.

The connection fees ranged from $5.00 to $50.00 with the usual fee either $25.00 or $50.00. The service charges were of four general types: (1) flat rate varying from $0.50 to $1.50 per month with $1.00 the most popular; (2) charge based on percentage of water bill with the percentage ranging from 15 to 50 per cent, and a minimum charge sometimes specified; (3) a regular rate schedule based on water consumption (2 towns only); and (4) rate based on the number of conveniences installed.

Only 3 communities had a separate scale of commercial and industrial rates. One of these based the charge for factories and institutions on the number of employees and the other two used a schedule of flat rates based on the type of business.

A study of sewage works financing showed that the outstanding general obligation bond total was about 12 times as great as the revenue bond total, indicating the relative popularity of the two methods of financing.

The report concludes that sewer charges now made in Tennessee are extremely low and bear little relation to the cost of providing approved service and treatment. The absence of any charge at all in 63 per cent of the communities studied indicates that sewer service is still largely supported by the general property tax levy in Tennessee.

M. R. GOLLY

A Practical Method for Predicting the Effects of Common Acids and Alkalies on the Survival of Fish. BY R. E. STIEMKE AND W. W. ECKENFELDER. *Bulletin No. 33.* The Department of Engineering Research, North Carolina State College (January, 1947). 45 pp.

The results of studies conducted on bluegill fingerlings using a number of acids and alkalies are tabulated and discussed and means are outlined for computing the lethal doses for acids and alkalies not used. Each test, using from two to four fish, was conducted in a 1-gal. glass jar filled with distilled water and acid or alkali.

In testing lethal concentrations of acids, sufficient acid was added to the water to give a pH value of from 4.18 to 6.6, and fish were then introduced. Additional acid was added in small doses at intervals of one-half hour in winter studies (December–February) and four hours in March and April studies, until the fish were killed. Several check tests indicated that if the fingerlings were not killed within the intervals selected they would live indefinitely. In all tests the last fish died within 5.5 hours after it was introduced into the jar.

It was found that the fish reacted differently according to either their stage of development or the season. In March and April they were killed at pH values higher than those producing death in

winter—4 to 8 per cent higher in the case of organic acids and approximately 18 per cent higher in the case of mineral acids. Results for acids in winter are summarized in the following table which shows the point at which the first and last fish in the jars died.

Death Points for Acids, Using One-Half Hour Dosing Intervals

Acid	Number of Fish Tested	First Death Point		Last Death Point	
		pH	Acidity	pH	Acidity
Hydrochloric, HCl	9	3.30	25	3.00	50
Nitric, HNO_3	6	3.30	25	3.15	36
Sulfuric, H_2SO_4	9	3.45	20	3.00	52
Phosphoric, H_3PO_4	3	3.11	78	3.11	78
Acetic, $HC_2H_3O_2$	9	3.75	85	3.65	140
Propionic, C_2H_5COOH	6	3.94	55	3.84	90
Lactic, $H(C_3H_5O_3)$	3	3.50	37	3.41	50
$HCl + H_2SO_4$	3	3.45	31	3.05	54
$H_2SO_4 + HC_2H_3O_2$	3	3.45	57	3.20	80
$HCl + HC_2H_3O_2$	3	3.50	62	3.47	78

Other tests were made using mixtures of three acids.

Tables are given showing the relation, both experimental and theoretical, of pH and acidity for the acids used.

In order to correlate the pH value and the acidity at the time of death, the following empirical formula was found to have merit:

$$(pH)\ (\log\ C)^n = N_E$$

where C = concentration as p.p.m. expressed as $CaCO_3$

n = constant depending upon type of acid

N_E = Eckenfelder's number.

Values of N_E Determined for the Average Death Point Based on One-Half Hour Dosing Intervals Using Pure Acids

Acid	Number of Fish	pH	Acidity	N_E
Hydrochloric	9	3.12	37	7.62
Nitric	6	3.22	29	7.07
Sulfuric	9	3.22	31	7.24
Phosphoric	3	3.11	78	7.20
Acetic	9	3.67	128	7.74
Propionic	6	3.89	80	7.45
Lactic	3	3.47	48	7.53

The exponent n considers the properties of the acid and for all the regular acids tested was approximately equal to $(1 + a)$, in which a is the degree of ionization. The method by which n was determined is shown for individual acids and mixtures.

N_E was found to be relatively constant at 7.4 at the average death point for all acids used.

Curves are plotted for each acid showing the variation between the pH value and N_E. It is explained that an industry by using these curves and with the knowledge of the death point for any acid, expressed either as pH or N_E, can "quickly determine the maximum reduction in pH that can be tolerated in a stream by discharge of an acid waste without harmful effect on the fish."

Alkalies were found to cause more violent death than acids. It was found necessary to use a four-hour dosing interval.

Average Death Point of Bluegill Fingerlings in Alkaline Solutions—Four-Hour Dosing Interval

Alkali	pH	Alkalinity ($CaCO_3$ p.p.m.)	No. of Fish Tested
NaOH	10.55	70	6
NH_4OH	9.60	31	6
Na_2CO_3	—	120	6
KI–NaOH	—	57	6

Because of limited data obtained no correlation was made of results obtained using alkalies.

W. A. HASFURTHER

Industrial Wastes in the Tanning Industry. By Robert Sutherland. *Ind. and Eng. Chem.*, **39**, 628–631 (May, 1947).

A description and flow diagrams for two types of tanning, vegetable and chrome processes, are given. The processing of sheepskins and shearlings is also described.

The wastes in the tanning industry are many and varied depending on the type of leather produced and on the process employed.

The basic types of tannery wastes, together with analyses, are shown in Table I. No analyses are given in Table I for degreasing and chamois wastes. However, the spent liquors from degreasing contain solvent and grease which should be removed prior to discharge. This also applies to oily wastes from chamois tanning.

Corrective measures recommended are based on the location of the plant and the antipollution regulations in that area. Utilization of byproducts and segregation of the wastes will do much to reduce the quantity and concentration. Treatment measures usually resort to screening, coagulation and sedimentation. "A few tanneries have employed sulfuric acid and alum or ferric salts to increase the efficiency of coagulation, with continuous pH measurement to control the process. Precipitation with carbon dioxide has been accomplished by bubbling flue gas through the mixed wastes."

Sludge is usually lagooned, although digestion has been tried. In the latter case careful control is necessary so as to maintain a uniform rate of digestion.

The author concludes his paper with the statement: "Furthermore, the expense of handling wastes should be considered a definite operating cost, and adequate provision made for this purpose. No comprehensive figures are available on disposal costs throughout the tanning industry, but estimates indicate that they may currently run as high as 0.2–1.0% of all operating costs, and they are certain to reach that level as requirements become more stringent."

H. Gladys Swope

Dairy Industry, Industrial Wastes. By H. A. Trebler and H. G. Harding. *Ind. and Eng. Chem.*, **39**, 608–613 (May, 1947).

Dairy wastes have a high pollutional value, but if the dissolved oxygen content of the receiving stream remains above 5 p.p.m., small amounts of dairy wastes are beneficial to fish life as the waste stimulates the growth of organisms upon which the fish feed.

The annual production of milk in the U. S. is now about 125 billion gallons.

The several types of dairy wastes are generally best treated separately. These wastes are: domestic sewage, boiler blowoff, backwash and regeneration rinse waters, cooling waters, spoiled products, by-product wastes, waste from drips and leaks, and wash waters.

Each of the above is discussed in detail together with its method of disposal. The first three can easily be handled in the

TABLE I.—Analyses of Basic Types of Tannery Wastes

Source of Waste	Total Solids (p.p.m.)	Soluble Solids (p.p.m.)	Suspended Solids (p.p.m.)	Volatile (%)	Ash (%)	B.O.D. P.P.M.	pH
Soak	15,000	13,510	1,490	1.23	0.27	1,200	6.6
Fleshing	—	—	—	—	—	—	—
Lime	26,000	18,840	7,160	1.2	1.4	2,770	11.6
Hair	—	—	—	—	—	—	—
Wash, all types	—	—	—	—	—	—	—
Bate	4,410	4,300	110	0.32	0.12	410	8.2
Pickle	61,200	59,960	1,240	0.59	5.53	790	2.4
Vegetable tan	18,400	17,110	1,290	1.50	0.34	5,500	5.0
Chrome tan	76,800	74,810	1,990	1.58	6.10	618	3.2
Bleach	—	—	—	—	—	—	—
Color and fat liquor	2,460	2,010	450	0.06	0.18	472	3.9
Degrease	—	—	—	—	—	—	—
Chamois	—	—	—	—	—	—	—

local sewage disposal plant. Cooling waters can be discharged directly to the stream except those used for vacuum pan condensers or in canned evaporated milk sterilizers. Cooling waters from these sources may carry some organic solids and have a high temperature.

"Disposition of spoiled products sometimes becomes a difficult problem; the wastes must not be dumped to clean streams or to city sewers in small cities. Sometimes the only practical method of disposal is to truck the products out for dumping in some isolated spots where no damage can be done.

"By-product wastes, such as whey, buttermilk, and excess skim milk, are the worst offenders as regards stream pollution.

"A sufficient number of large by-product plants should therefore be strategically located to pick up the available waste products from small plants within a given area. This would accomplish more toward elimination of pollution due to dairy waste than any other single method."

Good housekeeping is recommended as a means of reducing treatment costs. A reliable method for sampling according to flow is recommended.

A description and drawing of a continuous automatic sampler and hook gage installed in a 90° weir box is given.

Milk wastes can be treated by all methods used for domestic sewage; however, high-rate trickling filters are recommended as being the most economical. It is suggested that a coarse filter media be used (3 to 4.5 in. size). An allowance of 1 cu. yd. of filter medium per lb. of B.O.D. per 24 hr. is a safe limit if raw wastes have a B.O.D. of 1,000 p.p.m. or more, and an effluent with a B.O.D. of 60 p.p.m. is to be obtained regularly.

A flow sheet of the dairy industry is given together with two tables: one showing the approximate average composition of milk and dairy products, the other, standard milk process losses. In Table I are also shown the number of lb. of B.O.D. used by 100 lb. of product in a stream in 5 days at 20° C. and stated as per cent B.O.D., and the population equivalent based on the factor of 0.167 lb. B.O.D. per person per day in average domestic wastes.

The author ends his paper: "One thing is certain: It is worse than useless to build expensive waste disposal units if no economical way can be found for keeping them in good operating condition, preferably the year around. Fully automatic, absolutely foolproof disposal units have not yet been made to operate without any attention for days or months on end. Until such units are manufactured, the greatest progress in elimination of pollution due to dairy waste will be made by (a) improved waste saving devices and improved equipment and waste preventing devices within the milk plants, (b) new or improved methods of by-product utilization, and (c) dairy waste flow equalization and admission of dairy waste to city disposal plants."

A bibliography of 26 references is cited.

H. GLADYS SWOPE

TABLE I.—B.O.D. and Population Equivalent of Milk and Dairy Products

	B.O.D.[1]	Population Equivalent[2]
Whole milk	10.3	61
Evaporated milk	20.8	125
Skim milk	7.2	43
Dry skim milk	73.7	442
Sweetened skim condensed	50.2	301
Buttermilk	7.2	43
Whey (American cheese whey)	3.5	21
Cheddar cheese	60.0	360
Cream	39.9	239
Ice cream mix	29.2	175

[1] Pounds B.O.D. per 100 lb. of product.
[2] Population equivalent per 100 lb. of product.

Disposal of Slaughterhouse Waste. By G. BRÉVOT. *La Techn. Sanitaire* (France), Nov., Dec., 1946, Nos. 11–12, 79–87.

Samples of waste from abattoirs at Villette contained 347 mil. aerobic and 19.4 mil. anaerobic organisms per ml., as compared with 27 mil. total organisms in the sewage of Paris; organic suspended solids were 5,960 to 6,830 p.p.m. and the B.O.D. 595 to 788 p.p.m.

Complete biological treatment consisting of settling, chemical neutralization, trickling filters, and digestion produces an acceptable effluent. The final effluent must be disinfected. The superior council of Public Health in France now recommends that

municipalities work with specialists to "assure, with maximum security, proper treatment of abattoir wastes."

W. RUDOLFS

Microbiology of Beet Sugar Manufacture. By L. A. ALLEN, A. H. COOPER, ANNE CAIRNS, AND MARY C. C. MAXWELL. *Proc. Soc. of Appl. Bact.*, No. 1, 1–5 (1946).

The pulp water and pulp press water from the production of sugar from beet sugar contains 1.5 per cent sucrose with considerable amounts of suspended matter. In the return water circuit there is continuous recirculation of liquid to which make up water is added to compensate for the liquid withdrawn from the diffusion system. The circuit is maintained at 45° to 55° C., the water has ample nutrients at a pH value of 4.0 to 4.5, and receives agitation. These conditions are favorable for the development of thermophiles. High counts were obtained consisting of lactobacilli. These organisms when added to sterilized return-water brought the pH value down from 6.9 to 4.5 to 5.8 in 72 to 96 hours at 55° C. Other strains were able to bring the pH value down to 3.8 to 3.9 in 24 hours at 45° C.

Forty p.p.m. of chlorine added to return water was effective in destroying the numbers of bacteria by 99 per cent in 25 to 30 minutes at 55° C., and virtually eliminated the lactobacilli. When 19 p.p.m. of chlorine was applied continuously to the liquid in the battery supply tank, the pH value remained at 5.5 to 6.25 instead of going down to 4.0 to 4.5, and by consequence reduced the corrosion in the system by as much as 90 per cent. It had, however, no effect on the corrosions in the cells of the battery.

Conditions in the diffusion battery are different than those in the recirculation system. The diffusing liquid passes in through cells packed with cossettes, it is not subjected to agitation, and sugar content ranges from 1 to 12 per cent. The temperature varies from 50° to 75° C. Anaerobic conditions develop and sugar is broken down under this condition. In the water from the diffusion batteries two types of organisms were found consistently. These were thermophilic lactobacilli and thermophilic obligate spore forming anaerobes. These organisms are derived from the soil on the surface of the beet. The organisms may be responsible for an appreciable loss of sugar by fermenting it to organic acids and gases.

H. HEUKELEKIAN

Refinery Waste Disposal—XX. Methods for Handling Emulsions in Wastes. By W. B. HART. *Petroleum Processing*, 2, 691–698 (Sept. 1947).

Of the two types of emulsion that occur in refinery waste water, the stable, or oil-in-water type is the most difficult to handle. As water forms the continuous phase, these emulsions are miscible with water in all proportions. Originally milky in color, and of viscosity higher than water, they may be continuously diluted until only an opalescence remains. Diluted with natural water, the emulsion is eventually broken and the oil separates, but no practicable degree of sedimentation at the refinery will result in separation. These emulsions must be broken by chemical means.

The type of treatment chosen must be decided by laboratory and large scale trials. Sometimes heat alone will be successful, and that should be tried first. The effect of chemical agents can be studied most conveniently by using a low-power microscope and a long glass slide containing a number of depressions. A small amount of the emulsion is placed in each of the depressions, and a solution of the chemical agent added with a medicine dropper. Each test is then examined by moving the slide across the stage. Usually several chemicals will be found to have caused a break. These agents should then be investigated on a scale sufficiently large to estimate the economics of the process. This will narrow the choice to only one or two agents to be tried in a pilot plant.

Reagents for breaking emulsions should be salts of metals heavier than sodium, and should contain a metal ion that forms insoluble compounds with sulfonic, naphthenic, or other complex organic acids, because the sodium salts of these compounds are usually partly responsible for

emulsion stability. Soluble salts of calcium, magnesium, iron, and aluminum have been used for the purpose, but others may be satisfactory.

Batch chemical treatment may be used where relatively small quantities are produced each day. There should be two tanks, each capable of holding the amount of emulsion produced per day, plus the treating agent. Adjustable skimming arms should be provided, and agitation by compressed air is often used. The chemical agent may be added dry or in solution, depending on the agent or on convenience. A predetermined amount of agent is added to the emulsion while it is being agitated gently; agitation should continue for at least an hour. The mixture is then allowed to settle for several hours. The released oil (usually a soap) forms a layer on the surface; it should be delivered to some point for use as a fuel. The water layer should be examined to be sure that opalescence has disappeared and that the sample is almost completely clear.

Continuous chemical treatment differs little in fundamentals from batch operation. A series of treatment tanks is provided, and the waste, to which the chemical agent is added through a feeding device, flows continuously to one or another of the tanks, where agitation is provided. The charge in a mixing tank is pumped from time to time to a large settling tank, where the oil separates, is skimmed off, and the water discharged to a sewer. Samples must be taken from the line to the settling tank at intervals as a check on the completeness of the treatment. This system can also be used to handle water-in-oil emulsions and may be equipped for heat treatment where this is effective.

Flocculation probably provides the ultimate procedure for breaking stable emulsions, and it will also permit the most effective clean-up of effluents from oil-water separators where an especially high degree of treatment is demanded. This is a physico-chemical treatment wherein a chemical is added to form a gelatinous floc which is then agitated to form a particulate precipitate. In this operation even the finest particles become enmeshed and the precipitate settles, to yield a sparkling waste water. This treatment not only releases oil globules bound electrically in the emulsion, but it precipitates the stabilizing substances. Because of the tendency of the floc to pick up oil, where much free oil is present it should be separated before treatment so that it may be recovered and thus simplify sludge handling problems.

A flocculation plant will vary in design with local conditions. If the flow of emulsion is continuous and relatively constant, continuous treatment is indicated. If emulsion production is intermittent, holding tanks should be provided so the plant may be operated continuously from time to time as required. The plant will consist of a preliminary separator, flash flocculator, final clarifier, and sludge handling equipment. Plants of this kind usually contain patented features designed by various vendors, and the local problem should be discussed with their representatives.

The usual treating agents are various salts of aluminum or iron. The pH of the waste is important in that it affects floc formation, and hydrogen sulfide precipitates heavy metals to an extent that a dark effluent may be produced. Alum, at pH 6.5 to 8.0, may produce a floc too light to settle; in this case addition of finely divided clay will increase floc density. Iron salts, at pH 8.0 to 9.5, yield very good results where lime is added with the iron salt to adjust pH and prevent the formation of colloidal iron sulfide. Treatment costs may vary from $5 to $15 per m.g. of emulsion.

Water-in-oil emulsions usually contain a large proportion of oil. They occur in waste water channels as lively globs or layers. The film rupture chamber of an API oil-water separator is effective in breaking this type of emulsion. Heat treatment also is often effective, and the procedure is simple. When a suitable quantity of emulsion has been accumulated in a tank, it is heated with live steam until the temperature of the mass rises to 180° to 200° F. After being held at that temperature for a short time the mixture is allowed to settle for several hours. When sampling shows that separation is complete, the water layer is run to a sewer and the oil returned to the refinery for rerunning.

Sometimes a batch of emulsion is difficult to break with heat alone, and in such cases a combined heat and chemical treat-

ment plant demonstrates its value. Its design is like that for continuous chemical treatment, but heat exchangers are added to take advantage of such separation as occurs with heat alone. Chemical feed should be arranged to either precede or follow heating, to permit flexible operation to meet various conditions. A series of small settling tanks is to be preferred over one or two large ones for this type of treatment.

It is sometimes necessary to remove oil more completely than is possible by the procedures previously described, and this demands supplemental treatment of separator effluents. Simple filtration, bio-filtration, and flocculation are the three methods usually employed; they are listed in order of increasing degree of clean-up and cost. Flocculation was described above.

Simple filtration is often used where an abundance of salt marsh hay is available. In practice, four or more rectangular filter frames are provided so that one section may be out of service for cleaning at all times. The frames are packed with hay to a density dictated by experience, covers being used to compress the hay. The filter effluent is then allowed to percolate through the packed hay. The effectiveness of this method depends on both adhesion and absorption, and safe incinerators must be installed to burn the oil-soaked hay removed from the filters.

Where the volume of water is small, a graded sand and gravel filter, operated at not more than 2 gal. per sq. ft. per min., can be used satisfactorily. It is not necessary to install a backwash; it is better to scrape off the top few inches of sand and replace with fresh sand when the filter shows signs of clogging.

Trickling, or bio-filters, are in the developmental stage for cleaning up separator effluents, but their practicability has been established. They have the added advantage of reducing the B.O.D. of effluents.

RICHARD D. HOAK

New Problems in Sewage Treatment. *The Surveyor,* **107**, 123 (March 5, 1948).

A new type of synthetic detergent has been developed, general use of which creates problems for the sewage treatment works operator. With this material there is no dissociation on solution in water, in contrast to soaps which produce effective anion groups on dissociation.

Such a detergent is marketed in large quantities, particularly for scouring wool. It has good wetting properties for textiles. Other types are marketed for cleaning in industry and in the home. There is reason to believe that substantial use of these materials will result in difficulties at the treatment works. "Instead of the detergent plus associated emulsified impurities being precipitated naturally and retained in the sedimentation tanks, as with soap, these would pass unchanged to the oxidation stage, where the presence of additional colloidal solids, plus the extra oxygen demand, were both likely to prove sources of embarrassment."

If use of these products becomes widespread in industry, action may be necessary. The manufacturer should be prepared to treat their wastes before discharge to the sewer. If this is not practical, he should pay for the extra load placed on the sewage works.

Research should be carried on to find methods of dealing with wastes resulting from industrial use of these products.

T. L. HERRICK

References to Sewage Literature

July–December, 1947

By H. Gladys Swope

American City. Volume 62.

July, 1947 (No. 7).

"Dayton Adds Digesters," pp. 106–107.

"Old Faithful" (Operation Record of Sludge Gas Engines at Celina, Ohio), pp. 128–129.

"New Sewage Pumping Station" (Thief River Falls, Minn.), p. 139.

"Ten Years of Sewage Treatment Progress." Nathan I. Kass, pp. 140–142.

"$199,000 Saved by Gas Engine," p. 142.

August, 1947 (No. 8).

"Arlington County, Va., Makes Sewage Treatment Plans," pp. 86–87.

"Don't Destroy the Humus." J. P. Taylor, p. 87.

"Cincinnati's Sewer Improvement," p. 105.

"Our Sewage Reclamation Responsibility," p. 109.

September, 1947 (No. 9).

"A Sludge Dewatering Development," p. 102.

October, 1947 (No. 10).

"State Stream Pollution Abatement Today," p. 11.

"Sewage Sludge Fertilizer Value," pp. 94–95.

"Sewer Maintenance Organization." James H. Dowling, pp. 100–101.

November, 1947 (No. 11).

"Plastic Coatings for Sewage Works." C. G. Munger, pp. 112–113.

"Gary Gets Results," pp. 114–115.

December, 1947 (No. 12).

"What Caused the Suds in the Sewage Treatment Plant?" p. 99.

"Maintenance Principles for Water and Sewage Pumps," p. 107.

Engineering News-Record. Volume 139.

July 10, 1947 (No. 2).

"Sanitation Needs—How Much and Where?" pp. 42–43.

"Imbedded Coils Heat Sludge Digesters." L. L. Sphar, pp. 53–55.

"Sewage Plant Sells Sludge and Effluent." Leon W. Jackson, pp. 56–58.

"Dual Clarifier and Filter Structures Simplify High-Rate Treatment Process." A. J. Fischer, pp. 64–66.

July 24, 1947 (No. 4).

"How to Speed Up Slide Rule Work." Lee Johnson, pp. 112–114.

August 7, 1947 (No. 6).

"Modified Activated Sludge Plant Replaces Imhoff Tank Installation." E. R. Schofield, pp. 192–195.

August 21, 1947 (No. 8).

"Report on China's Sanitation Progress," pp. 260–261.

September 4, 1947 (No. 10).

"Water-Sewerage Needs Are Analyzed," p. 340.

"Pumping Can Be Simplified for Small Sewage Disposal Plants." William J. Wenzel, pp. 341–342.

"Sludge Depth Indicator." James H. Blodgett, p. 342.

September 18, 1947 (No. 12).

"Grit and Grease Chamber Reduces Sewer Cleaning and Pollution Problems." Frank L. Flood, pp. 391–393.

"Constructing a Big Sewer by Tunneling," pp. 408–410.

October 16, 1947 (No. 16).

"San Francisco Examines Sewer in Place." Ralph G. Wadsworth, pp. 536–538.

November 27, 1947 (*No. 22*).
"Diversion Factors for Combined Sewers Based on Sewage and Stream Analyses." Robert J. Theroux and Robert L. Meek, pp. 734–736.

December 11, 1947 (*No. 24*).
"Chlorination Curbs Beach Pollution," pp. 801–803.
"Sewer Gate Operation by Remote Control." L. L. Bradish and F. C. Lorenzen, pp. 812–813.
"Waste Treatment Plants Put Under Construction," p. 822.

December 25, 1947 (*No. 26*).
"Gas Fire in Sewer Manhole Traced to Sanitary-Fill Operation," p. 863.
"Submerged-Weir Discharge Studies." James R. Villemonte, pp. 866–869.
"Mining a Deep Sewer in Unstable Soil," pp. 882–885.

Public Works. Volume 78.

July, 1947 (*No. 7*).
"Milk Losses and Milk Waste Disposal." Philip S. Davy and Melvin J. Noth, pp. 22–23, 66.
"Trickling Filters," pp. 31–37.

August, 1947 (*No. 8*).
"Backwashing for a Trickling Filter Installation," p. 21.
"Individual Sewage Disposal—Small Septic Tanks for the Housing Program," pp. 28–30.
"Trickling Filters," pp. 39–43.

September, 1947 (*No. 9*).
"Sewer Rental Data," pp. 19–20, 32.
"The Treatment of Strong Wastes." A. W. Banister and R. J. Ellison, pp. 26–27, 30.
"How to Design Imhoff Tanks and Trickling Filters for Schools, Camps, and Hotels," pp. 33–34.
"Detroit Sewage Disposal and Water Rates," p. 36.
"Stream Pollution Standards for Washington State," p. 44.
"How to Inspect Sewers and Drains During Construction," p. 44.

October, 1947 (*No. 10*).
"Operation Data on Sewage Treatment at Detroit," p. 33.

November, 1947 (*No. 11*).
"Performance Data on Tangential Influent Clarifiers." G. R. Herzik, Jr., H. L. Dabney, and R. H. Weiss, pp. 22–23.
"How to Make Good Sewer Pipe Joints," p. 38.

December, 1947 (*No. 12*).
"Observations on 2-Stage Biofilter Operation," pp. 24–25, 55.
"Model Waste Treatment Plants," pp. 29, 33.

Sewage Works Engineering. Volume 18.

July, 1947 (*No. 7*).
"What Lies Ahead in the Sewage Works Field?" Francis S. Friel, pp. 355–356, 390.
"Portland's Digested Sludge to Be Discharged into River." John W. Cunningham, pp. 357–358, 375.
"Major Treatment Program for San Francisco," pp. 359–361.
"Hyperion Plant to Clean Up Southern California Beaches," pp. 362–365.
"East Bay Cities Plan Plants to Cost $23,000,000." Darrell A. Root, pp. 366–369.
"Los Angeles County Increases Capacity from 4 to 200 M.G.D." A. M. Rawn, pp. 370–372.
"California Plans $200 Million Treatment Program." Edward A. Reinke and John T. Norgaard, pp. 373–375.
"Oregon Ready to Build and Finance Plants." Curtiss M. Everts, Jr., p. 376.
"Washington Sewage Planning at Highest Level." Emil C. Jensen, pp. 377, 392.

August, 1947 (*No. 8*).
"Public Health Service Sees Need of $7.8 Billion Sanitation Program," pp. 418–421.
"'Salad Bowl' Wastes Treated at Converted Plant." Harry N. Jenks, pp. 422–424.
"Raw Sludge Steam Heated." Eric V. Quartly, pp. 425–426.
"Cost Analysis of Activated Sludge Plant, Abington Township, Pa." Francis S. Friel, pp. 427–428.
"Review of Recent Injury Suits." Leo T. Parker, pp. 431–432.

"Acid Wastes Affect Detroit Sewers," p. 433.

"Operation of Mechanical Sludge Collectors," pp. 434–436.

September, 1947 (No. 9).

"Flow Coefficient Tests on Transite Outfall." A. J. Maahs, pp. 473–475.

"Electrolysis and Corrosion Corrected by Zinc Metallizing." T. R. Lovell, pp. 476–477.

"Explosion Hazards in Manholes, Causes and Protective Measures." Reuben F. Brown, p. 478.

"Maintenance of Mechanical Sludge Collectors," pp. 483–484.

October, 1947 (No. 10).

"Garbage Grinding Planned for The District of Columbia." Ralph E. Fuhrman, pp. 518–520.

"Studies of WPA Projects." George D. Babcock, pp. 521–525.

"Sewage Disposal in China a Major Problem for the Future." John R. Snell, pp. 526–527.

"Fort Wayne Sewage Gas Engine Nets $199,000 in Six Years," p. 527.

"To Cease Pollution of Lake," p. 527.

"Legal Sewer Construction." Leo T. Parker, pp. 531–532.

"Cross-Connection Hazards at Sewage Plants," pp. 534–535.

November, 1947 (No. 11).

"Distillery Pollution Reduced by Feed Recovery Process." C. W. Klassen and A. P. Troemper, pp. 566–571.

"West Virginia Establishes Four Stream Quality Classifications," p. 578.

December, 1947 (No. 12).

"Growing Pains of a Sewage Treatment Plant." E. J. M. Berg, pp. 616–619.

"The Plant Operator Has Responsibilities." Francis S. Friel, pp. 620–621, 640.

"Recirculation Tests on High-Rate Filter." Clyde C. Kennedy and Walter C. Roberts, pp. 622–624.

"Brass Wastes Detrimental to Digesters at Kenosha, Wis." H. T. Rudgal, p. 626.

Water and Sewage Works. Volume 94.

July, 1947 (No. 7).

"Mechanical Sewer Cleaners Simplify Sewer Maintenance." Reuben F. Brown, pp. 249–251.

"The Handling and Use of Chlorine," pp. 253–258.

Reference and Data Section.

"Public Relations in Water and Sewage Treatment Plants." Walter A. Sperry, pp. R-17—R-19.

"Centrifugal Pumps." H. E. Beckwith, pp. R-21—R-24.

"Curve for Determining Flow in Components of Parallel Pipe Systems." John J. Baffa, pp. R-39—R-42.

"Practical Electricity in the Plant." Marsden C. Smith, pp. R-59—R-64.

"Weights per Cubic Foot of Dry Chemicals Used in Water and Sewage Works," p. R-64.

"Preparation of Metals for Painting." R. E. Gwyther, pp. R-72—R-73.

"Chart for Converting Grains per Gallon to Pounds per Million and the Reverse," p. R-120.

"Chemical Weed Control." R. F. Goudey, pp. R-121—R-126.

"Some Practical Aspects of Handling Chlorine." Chris F. Bingham, pp. R-127—R-129.

"Contemporary Chlorination Practices." Harry A. Faber, pp. R-131—R-133.

"Modern Financing of Sewage Works," pp. R-161—R-165.

"Sewer Service and Maintenance." Edward P. Decher, pp. R-166—R-169.

"Useful Technic in Ground Water Infiltration Studies." Charles A. McLoughlin, pp. R-169—R-170.

"Proper Sewer Jointing." William A. Goff, pp. R-171—R-172.

"Sewage and Sludge Pumping." Henry Ryon, pp. R-173—R-176.

"Maintenance of Sewage Pumping Stations." A. L. Soden, pp. R-177—R-179.

"Improved Method of Velocity Control in Grit Chambers." Ralph J. Bushee, pp. R-180—R-182.

"Design of Control Flumes for Grit Chambers." W. E. Howland, pp. R-182—R-183.

"Control of Odorous and Destructive Gases in Sewers and Treatment Plants." Charles C. Hommon, pp. R-185—R-187.

"Operation of Activated Sludge Plants." Gail P. Edwards, pp. R-191—R-195.

"Sludge Density Control." John A. Tapleshay, pp. R-197—R-199.

"Sludge Index Control by Chlorination." J. Kenneth Adams, pp. R-199—R-200.

"Cleaning Air-Diffusion Media." John J. Wirts, pp. R-201—R-203.

"Gas Engine Maintenance and Operation." L. S. Kraus, pp. R-205—R-209.

"The Scum Problem from the Operators' Standpoint." Joseph Doman, pp. R-211—R-212.

"Theory and Operation of Separate Sludge Digestion Units." L. L. Langford, pp. R-213—R-214.

"Protection of Motors and Controls Against Moisture." H. V. Crawford, p. R-215.

"Operating and Experimental Observations on Digestion of Garbage with Sewage Solids." David P. Backmeyer, pp. R-217—R-221.

"Sludge Incineration." E. T. Killam, pp. R-225—R-226.

"Reducing Cost of Sludge Removal." Walter A. Sperry, pp. R-227—R-228.

"Sludge as Fertilizer." Le Roy W. Van Kleeck, pp. R-229—R-230.

"Contents of Conical Piles," p. R-230.

"Sludge Lagooning." Don E. Bloodgood, pp. R-231—R-234.

"How to Use DDT for Insect Control." L. F. Warrick and G. F. Bernauer, pp. R-235—R-237.

"Nomograph for Determination of Sludge Filtration Data." Charles M. Gard, pp. R-239—R-240.

"Dosage Control in Sewage Chlorination." George E. Symons, pp. R-243—R-245.

"Killing Roots in Sewers with Copper Sulfate." J. W. McAmis, p. R-245.

"An Inexpensive Hypo-Chlorinator." J. R. Snell, p. R-246.

"Sewage Plant Records and Operating Reports." L. S. Morgan, pp. R-247—R-248.

"Use of Charts in the Analysis of Sewage Operation." W. Vincent Barry, pp. R-249—R-251.

"Water Waste Detection by Observing Sewer Flows." D. D. Gross, p. R-252.

"Evaluation of Sewage Works Data." George E. Symons, pp. R-253—R-254.

"Equipping the Sewage Plant Laboratory." Norman C. Wittwer, pp. R-255—R-260.

"Equivalents and Conversion Factors," pp. R-262—R-263.

"Contents of Horizontal Cylinders." J. Tarrant, pp. R-264—R-266.

"Chart for Determination of Pumping Costs," p. R-266.

"Chart for Determining Head, Capacity, Efficieney, Horse Power with Any Three Conditions Known," p. R-267.

"Flow Powergraph," p. R-268.

"Pipe Flow Diagram," p. R-269.

"Hydraulic Entrance Losses," p. R-270.

"Flow of Water in Concrete Pipe Lines," p. R-271.

"Chart for Capacity of 60° and 90° V-Notch Weirs," p. R-272.

"Chart for Capacity of Rectangular Weirs," p. R-273.

"Calculation of Areas, Volumes, Surfaces Reduced to Simple Terms," pp. R-274—R-276.

August, 1947 (No. 8).

"Treatment Works for Plating Wastes Containing Toxic Metals and Cyanides." George E. Barnes, pp. 269–271.

"Graphic Heat Loss Computation for Sludge Digesters." John G. Montgomery, pp. 287–291.

"Tables for Computing Heat Losses from Digesters." Henry B. Candee, pp. 292–293.

"Water and Sewage Works Needs of the United States," pp. 294–297.

"Still More Water and Sewage Works Projects," pp. 299–300.
"Biofiltration Experiences at Columbia (S. C.) Army Air Base." James M. Brown, pp. 301–303.
"Water and Sewage Patents," p. 304.

September, 1947 (*No. 9*).
"Hydraulics for the Practical Water Works Man." Robert W. Angus, pp. 337–340.
"The Sewer Scooter." M. W. Loving, pp. 347–348.
"Sand Filtration of Some Organic Wastes." Willem Rudolfs and Victor Del Guercio, pp. 349–351.

October, 1947 (*No. 10*).
"Significance of Legislation Forbidding Strikes by Public Employees." Wendell R. LaDue, pp. 353–358.
"Diesel and Gas Engine Equipment." A. M. Boehm, pp. 379–383.

November, 1947 (*No. 11*).
"Hydraulics for the Practical Water Works Man." Robert W. Angus, pp. 405–408.
"Public Relations Program Pays Off." W. M. Kunsch, pp. 424–426.
"Proposed Water Pollution Legislation." M. LeBosquet, Jr., pp. 427–430.
"A Simplified Vacuum Filter." T. R. Komline, pp. 431–432.
"Water and Sewage Patents," p. 432.

December, 1947 (*No. 12*).
"Responsibilities of Water and Sewage Works Operators." Francis S. Friel, pp. 435–438.
"Pulp and Paper Mill Reduces Pollution of Clarion River in Pennsylvania." Christian L. Siebert, pp. 449–451.
"Cost of Heating Glass Covered Sludge Drying Beds." Albert B. Kozma, pp. 456–462.

MAKE YOUR HOTEL RESERVATIONS FOR THE DETROIT CONVENTION

The Hotel Statler at Detroit, headquarters for the Twenty-First Annual Meeting of the Federation in October, will be able to accommodate most of the out-of-town registrants. Some rooms will also be made available by the Book-Cadillac Hotel, located about three blocks from the Statler.

Requests for room reservations should be addressed directly to the hotel. Note that the technical program will open on Monday morning, October 18, and will close at noon on Thursday, October 21.

WRITE NOW FOR YOUR RESERVATIONS!

Book Reviews

Industrial Waste Disposal for Petroleum Refineries and Allied Plants. By W. B. Hart. Petroleum Processing, Cleveland, Ohio. First Edition, 1947. Price $4.00.

A desk reference volume of 103 pages (8½ by 11 in.), consisting of 20 articles divided into 5 sections, as follows:

Economic and Legislative Aspects of the Industrial Waste Problem

Article	Pages
1—Industry's Relation to the Problem.	4
2—Industry and the Authorities.	3
3—Refining Industry Has Important Role in Water Conservation Program.	2

Kinds of Wastes

4—Classifying Wastes is First Step in Disposal.	7

Effects of Industrial Wastes

5—Properties of Surface Waters Affected by Refinery Wastes.	4
6—Waste Oils Escaping to Surface Waters May Cause Many Kinds of Damage.	4
7—Chemicals Present in Escaping Wastes Can Damage Waters for Many Uses.	5
8—Refinery Wastes Can Stop Oxygen Supply, Causing Water Pollution and Killing Life.	5

Preliminary Investigations

9—Oil Savings, Plant Economies are Dividends from Organized Anti-Pollution Program.	4
10—Preventing the Fouling of Cooling Waters Reduces Plant's Waste Disposal Costs.	4
11—Designing Disposal System for Discharge of Uncontaminated Waste Waters.	3
12—Improper Control of Storm Run-Off Water May Nullify all Waste Treatment Efforts.	4
13—Storm Run-Off in Open Sewers and Ditches Can Be Accurately Measured by Weirs.	4
14—Disposal Needs Based on Graph Method for Finding Run-Off to Rainfall Ratio.	3

Treatment of Oil-Containing Wastes

15—Basic Natural Law—Not "Rule-of-Thumb"—Should Apply in Sedimentation Methods.	4
16—Four Factors Are Major Controls in Design of an Economical Oil-Water Separator.	6
17—Designing Primary Section and Accessories of an Effective Oil-Water Separator.	6
18—Secondary Section of Oil-Water Separator Effects Final Clean-up of Refinery Wastes.	4
19—Modifications of Oil-Water Separators to Meet Specialized Applications.	6
20—Methods for Handling Emulsions in Wastes.	6
Nomenclature.	1
References.	4
Index.	4

The articles which form this book were first published as a series in *Petroleum Processing*. They were intended primarily for refinery engineers and were designed to serve as a source work on waste disposal for the refinery industry. The first three articles are devoted to acquainting the reader with the industrial waste disposal problem in general and industry's relation to this problem, together with a brief review of the economic and legislative background of the problem.

The remaining articles develop in logical sequence the various aspects of solving the waste disposal problem for refineries and allied plants. Although dealing primarily with refinery problems, a large part of the material is so basic that it is applicable to many kinds of waste control. For example, methods of determining, measuring, and controlling industrial wastes are covered in a thorough and wholly practical way, with appropriate sketches and diagrams. The articles on the reduction and prevention of waste losses within the processing plants should be of particular value to the industry.

Those experienced in the general field of industrial waste disposal will find some of the material covered to be basic and elemental to this field. When viewed in relation to the group for which these articles were specifically written, however, the inclusion of such subject matter becomes logical. Considerable material has been included pertaining to specific problems of refinery wastes disposal which is not included in the working knowledge of most of those whose experience lies in the other branches of industrial wastes disposal. This is particularly true of the material concerning the design of oil-water separators and the methods of handling emulsions in wastes.

For the man who works directly with wastes disposal problems of the petroleum and allied industries this new book should be a valuable ready reference. It will also prove to be a useful addition to the general library of all interested in industrial wastes disposal.

The author has had extensive experience in the refinery waste disposal field where he is widely known and highly regarded. The text has been developed from his 20 years experience with refinery waste disposal problems.

Finding of material to specific problems is facilitated by a detailed index. The bibliography of 174 references is comprehensive and should be useful for further study of any particular phase of the general refinery disposal problem.

All of the 20 articles comprising the text have been given detailed reviews in the Reviews and Abstracts sections of THIS JOURNAL, as indicated below:

Article	Journal Issue
I–VI (incl.)	Nov. 1946, pp. 1245–1249
VII–IX (incl.)	Jan. 1947, pp. 133–137
X–XII (incl.)	May 1947, pp. 541–544
XIII–XV (incl.)	July 1947, pp. 708–710
XVI–XVII (incl.)	Sept. 1947, pp. 956–957
XVIII	Nov. 1947, pp. 1111–1112
XIX	Mar. 1948, pp. 363–365
XX	May 1948, pp. 596–598

S. C. MARTIN

Field Practice—Volume Three of Data Book for Civil Engineers. BY ELWYN E. SEELYE. John Wiley and Sons, Inc. First Edition, 1947. Price $4.50.

A pocket reference book of 360 pages, comprising two parts which are divided into several sections, as follows:

Title of Section	Pages
Part I—Inspection	188
Typical Heavy Construction Equipment	7
Concrete	39
Masonry	4
Structural Steel	11
Welding	11
Bridges	6
Painting	1
Foundations on Soil	2
Pile Driving	5
Timber	8
Ropes and Cable Strength	1
Varieties of Knots	1
Soils	35
Aggregates	4
Grading	1
Bituminous Paving	26
Sanitary Construction	1
Pipe Laying	16
Miscellaneous	7
Part II—Surveying	113
Topographic Survey	4
Construction Stakeouts	5
Circular Curves	15
Transition Curves	10
Vertical Curves	6
Railroad Turnouts and Crossovers	1
Earthwork Computations	8
Leveling	1
Transit Problems	7
Allowable Errors	2
Determination of True North	4
Instruments and Their Adjustments	20
Taping	1
Mapping	6
General Tables and Information	16
Index	

"Field Practice" is the third and final part of Data Book for Civil Engineers (Vol. I—Design; Vol. II—Specifications and Costs). It is a handy size field reference volume designed for the use of the field engineer or inspector for inspection of almost any line of civil engineering construction work. Its purpose is to enable the field engineer to take to the field the basic data required.

The book contains outlines on inspection procedures and check lists on the items listed above. It also presents material on the conducting of field tests as well as necessary data tables and report forms. Surveying is covered in considerable detail.

Only a small part of the book is devoted to sewage works construction as such. The section on Sanitary Construction consists of a very sketchy, elementary, and generalized check list for inspectors of sewage treatment plant construction. The brief check list on pipe-laying inspection is also sketchy, generalized, and somewhat academic. Standard ASTM and AWWA pipe tables are given together with a table for Transite water and sewer pipe and the ASA table for standard weight and thickness of C.I. pipe.

"Field Practice" should be of considerable value as an on-the-job general reference and check list for construction inspectors. The layout and format of the book are excellent. Illustrations have been liberally and effectively used. It is believed that the inclusion of several blank pages in each section for the entry of additional notes by the user would have improved the field-use value of this book.

S. C. MARTIN

Professional Opportunities

Regular Corps Appointments for Junior Assistant Engineer Officers in the U. S. Public Health Service

A competitive examination for appointments in the Regular Corps in the U. S. Public Health Service in the grade of Junior Assistant Sanitary Engineer (2nd Lieutenant) will be held during June, 1948.

A Regular Corps appointment is permanent in nature and provides an opportunity for a qualified engineer to make a life career of engineering as it relates to the protection and promotion of the public health. Assignments to duty are made with consideration of the officer's abilities and training. Such assignments include general sanitary engineering, industrial hygiene, malaria and typhus control, milk and food sanitation and research. Provision will also be made for additional postgraduate and other in-service training as required.

Entrance pay for the Junior Assistant grade with dependents is $3,391 a year. Promotions are at intervals up to and including the grade of Senior Sanitary Engineer, which corresponds to the rank of Lieutenant Colonel, at $7,018 a year. Promotion to grades above Senior Sanitary Engineer is by selection. Retirement pay after thirty years service or at the age of sixty-four is $4,950 a year. Full medical care including disability retirement at three-fourths base pay and thirty days annual leave with pay are provided.

An applicant for the Junior Assistant grade must (1) be a citizen of the United States at least eighteen years of age, (2) have a degree in one of the several branches of engineering, from a school of recognized standing.

Each applicant will receive a physical examination by a medical officer of the Public Health Service and a written examination, and will be rated by a Board of Officers as to professional knowledge and general fitness.

The written professional examination for the Junior Assistant grade will be in the following subjects as they relate to courses of study generally provided in engineering schools of recognized standing:

1. Basic Science Principles (including Chemical, Biological, Physical, and Social Sciences).
2. Basic Science Application.
3. Engineering Practices.
4. Public Health Methods and Procedures.
5. Specialty.

Application forms and additional information may be obtained from the Surgeon General, U. S. Public Health Service, Washington 25, D. C. Applications should be submitted without delay and must be received prior to June 1, 1948. The written examination is scheduled for June 21, 22, and 23, and will be held at designated Service Stations convenient to the candidates. Applicants will be notified regarding the date and location of the oral examinations. Transportation expenses to and from, and the cost of maintenance at the place of examination must be assumed by the applicant. The written examination will require approximately 3 days.